COAL
IN GREAT BRITAIN

THE COMPOSITION, STRUCTURE, AND RESOURCES OF THE COALFIELDS, VISIBLE AND CONCEALED, OF GREAT BRITAIN

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PREFACE

THE present work is intended to supply mining engineers, mine owners, and mining students with a concise account of the more important facts relating to the geology of coal generally, and to the composition, structure, and resources of the coalfields of Great Britain in particular. It is hoped, also, that the subject is treated in a manner which will prove useful to those who, though not directly concerned in getting coal, are dependent on coal for industrial purposes, and also to those who take a scientific interest in this important industry.

In dealing with so comprehensive a matter within a comparatively small space, many details that are often of great local importance are necessarily omitted; and for the same reason controversial matter has been avoided.

Chapters I. to VIII., which may be regarded as introductory, are reproduced, with many additions, from the author's work on the 'Geology of Coal and Coal-Mining,' which formed the first volume of Arnold's Geological Series, and which is now out of print. The rest of the book, dealing with the coalfields of Great Britain, is in part a condensation of personal experience and observations in the field during a period of thirty years, and of facts collected from various publications, more especially those of the Geological Survey of the United Kingdom and of the Federated Institute of Mining Engineers, to which the author here wishes to acknowledge his indebtedness.

WALCOT GIBSON.

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COAL IN GREAT BRITAIN

CHAPTER I

VARIETIES—CHEMICAL AND PHYSICAL CHARACTERS

THE term 'coal' includes those solid combustible substances which have resulted from the decomposition and alteration of once living vegetable organisms, now occurring in a fossil state in geological formations of various periods. Since the stages reached in the decomposition and alteration vary within wide limits, and the changed vegetable matter is more or less mixed with foreign material, it is obvious that what is coal and what is not coal cannot be satisfactorily defined. Solid bitumens, soluble in naphtha or benzene, and whether of organic or of inorganic origin, are excluded. Bituminous coals are soluble in pyridine to some extent, leaving a residue that does not coke. Anthracite is insoluble.

Sulphur in combination with iron is usually present in coal, and in the cleanest coal there are always certain impurities, consisting of silica, iron oxides, silicates of alumina, potash, and soda. These foreign substances constitute what is known as the ash.

Plant tissues and coal agree in the essential constituents of both being some combination of carbon with hydrogen, oxygen, and nitrogen, the carbon being largely in excess of the other elements in an ash-free coal. The main bulk of plants, whether of a high or low organization—a forest tree or a moss plant—consists of an organic substance remarkably uniform in composition. In each of these plants, separated so widely in organization, the carbon percentage varies between 48 and 51 per cent., the hydrogen between 5·9 and 6·5 per cent., and the combined oxygen and nitrogen between 41·8 and 44·5 per cent. The inference is drawn that the chemical nature of this organic substance has been the same throughout geological time.

While plant tissue throughout the vegetable world possesses a remarkably uniform composition, parts of a plant vary in composition, and one part of a plant differs in the proportion of its chemical components from the corresponding part in another plant. For example, leaves, leaf-stalks, and bark are richer in carbon, but are poorer in hydrogen and nitrogen, and contain more ash than spores, seeds, and cuticles. Since the different kinds of coal are based on differences in chemical composition, a coal formed out of spores will differ *ab initio* from one derived from the alteration of bark and leaves.

Ordinary domestic coal usually consists of obviously distinct layers—one bright and glistening, termed 'bright coal,' and another layer that is dull-black, silky, and fibrous, and known as mineral 'charcoal' or 'mother of coal' (*fusain, houille dalöide, faserkohle,* of Continental writers). Coal, in fact, like any other sedimentary rock, has in most cases a distinctly stratified appearance. Along the dull layers, what look like fragments of charred vegetable tissue—either leaves, leaf-stalks, bark, or wood—are often clearly distinguishable. The appearance of charring is not attributable to the action of heat, but represents wood that was affected by dry rot. In the bright layers organic structure is not evident, but as in the Better Bed Coal of Yorkshire, to cite a well-known example, these bright layers can be seen under the microscope to consist largely of spores and sporangia, especially when the coaly substance has been previously treated with a solution of sodium carbonate, or, better still, with a mixture of nitric acid and potassium chlorate, followed by ammonia. The difference in chemical composition of the dull and bright layers agrees with that of the organic materials composing them; the layers of mineral charcoal, or dull layers, are richer in carbon, but contain more ash than the bright layers. In the case of a coal from South Wales, the dull layers give a composition of: Moisture, 1·68; volatile matter, 14·71; fixed carbonaceous residue, 77·17; ash, 6·44; and the bright layers a composition consisting of: moisture, 1·75; volatile matter, 31·63; fixed carbonaceous residue, 63·96; ash, 2·66. However, it is not safe to assume that coals in which spores are abundant have originated entirely from spores, since these parts are present owing to their greater resistance to destruction by biological and chemical action than plant tissues.

Besides the organic compounds, all plants, as previously mentioned, contain mineral salts, which are not only different for distinct plants, but also vary greatly both in quantity and nature in different parts of the same plant. *Lycopodium clavatum*, one of the commonest of the British club mosses, contains 4·7 per cent. of ash, and a closely allied species, *Lycopodium chamæcyparissum*, as much as 6·7 per cent. of ash. The ash contained in forest trees, on the other hand, rarely exceeds 2 per cent., and the spores of the Lycopodiaceæ also contain an appreciably smaller quantity of ash than the other tissues. The character of the ash is most marked in *Lycopodium* and in *Sphagnum*, the common bog moss, both of which possess the power of dissolving alumina out of the soil. From its insolubility in water, alumina remains after the plant has rotted, and after a large proportion of the other soluble mineral constituents has been dissolved out and carried away. It is interesting to find that the ash present in the mineral charcoal of the Better Bed Coal contains from 28 to 33 per cent. of alumina. Salts of iron and lime, though more soluble than alumina, are less so than salts of potash and soda. The sulphur present in all plants unites to form more or less insoluble compounds. Thus in decaying vegetation certain mineral salts which existed in the living plant will be concentrated, while others will be carried away in solution. Apart, then, from the mineral matter—clay and shale (forming the bulk of the ash observed in burning most house coals)—introduced from extraneous sources to the spot where the decaying vegetable matter was accumulating, some proportion of the inorganic salts found in coal are due to the aggregation of the insoluble salts present in the living matter from which the coal was derived.

Some coals consist of an amorphous mass without any trace of organic structure. The theory that such coals have resulted from eruptions of bitumen, though lately revived, does not receive wide acceptance. But it is far from unlikely that animal matter has not to some extent contributed to the formation of certain kinds of coal.

Changes affecting the decayed vegetation subsequent to its burial beneath sediments, and those resulting from earth pressure and other geological agencies, are dealt with in a succeeding chapter. Each agency has had some effect in producing the varieties of coal recognized by the chemist or in commerce. In describing the several varieties of

coal as commonly designated, it is usual to commence with those coals of which the organic origin is the least obscured, and then to pass to those in which the original organic structure is partially, or it may be wholly, indistinguishable even under the microscope. Peats and lignites, though usually excluded from the coal series, will be considered first, since these two kinds of vegetable fuel occur in a fossil state, and also illustrate some of the stages through which vegetable tissue may pass.

Peat.—The purest, thickest, and most extensive accumulations of vegetable débris at the present day occur in peat-bogs and swamps. Peat-bogs are mostly found in the Northern Hemisphere, and extend up to the polar limit of vegetation, the 56th degree north parallel forming the chief zone.

In Ireland peat-bogs cover an area of over 3,000,000 acres, and in some places the peaty accumulations attain a depth of over 50 feet. France contains large tracts of peat, and Russia the largest of all. Except in Madagascar, there are few peat-bogs of any size in the Southern Hemisphere. The swamps of Virginia and those in the deltas of the Ganges and Brahmaputra afford examples of areas where decaying vegetation is accumulating at the present day. Swamps differ from peat-bogs by the presence of free circulating waters, a fact of some importance in determining the stage to which decomposition of the vegetable matter will proceed.

The rate of growth of peat varies considerably. It is stated to be as much, under exceptionally favourable conditions, as 26 inches in a century; but immersion and low temperature tend to retard its accumulation. The upper layers in a peat-bog are light coloured, and the vegetable origin is obvious; but deeper down the layers become darker in colour, until near the bottom they are almost black, and to a considerable degree have lost all visible signs of organic structure. In the 'Red Bogs' of the central plains of Ireland the organic matter, partly in a living state, forms a layer from 2 to 6 feet in thickness, termed the 'clearing'; beneath this comes a layer of 'white turf,' passing down into 'brown turf,' and thence downwards, until at the bottom of the bog comes the 'black' or 'stone turf.' Each layer consists of laminæ increasing in the number per square foot from above downwards. The 'black turf' is the most valuable for fuel purposes, giving

out when dried a strong heat and brilliant light. It is interesting to note that the percentage of ash is usually highest in the 'black turf.' In some Scottish peat-bogs an interesting alternation of forest beds with peat is observed in a following upward sequence: (1) First Arctic Bed; (2) Lower Forestian; (3) Lower Peat-Bog; (4) Second Arctic Bed; (5) Upper Peat-Bog; (6) Upper Forestian; (7) Recent Peat.

Mosses, monocotyledonous, and, more rarely, dicotyledonous plants enter into the formation of modern peats.

The composition of peat varies within wide limits. The percentage of carbon ranges from 50 to 64; hydrogen, 4·5 to 6·8; oxygen and nitrogen, 28·6 to 44·0. A large quantity of moisture is usually present, air-dried peat containing as much as 15 per cent. Compared with fresh plant tissue, the carbon-hydrogen ratio for peat is 9·8 and 7·2 for fresh tissue; and the carbon-oxygen ratio 1·8 and 0·9 respectively.

A carbonaceous substance, called 'doplerite,' was first found in a peat-bog in Austria. It is a black, gelatinous substance, becoming brittle after exposure to air and assuming a coaly appearance. It is insoluble in water, ether, and alcohol, but is entirely dissolved by caustic potash. Dried at 212° F., its composition is: Carbon, 48·06; hydrogen, 4·93; oxygen, 40·07; nitrogen, 1·03; ash, 5·86. At Scranton, Pennsylvania, a similar-looking substance was found at the bottom of a peat-bog, but with an analysis showing carbon, 28·98; hydrogen, 5·17; nitrogen, 2·45; oxygen, 56·98; ash, 6·40.

Peat belongs to the Quaternary or latest period in the geological record. A few thin bands are Pre-Glacial, and some are Inter-Glacial; but the most extensive areas of peat are of recent formation, though at the present day peat is not forming to any appreciable extent. It is almost certain that hill peats and lowland peats are not represented on a large scale in the geological formations older than the Quaternary, though 'dirt beds' or ancient soils have been preserved in the secondary formation of this country.

The Great Dismal Swamp of Virginia and North Carolina is the best-known example of a swamp. It extends over a rectangular area forty miles long from north to south, and twenty-five miles from east to west. A small lake, about seven miles in its longest diameter, occupies nearly the centre of the swamp, with a maximum depth of between 6 and 15 feet. The thickness of the vegetable soil varies

from 10 to 15 feet, and is stated to increase at a rate of $\frac{1}{10}$ inch in a year.

Lignite.—This variety of fuel in physical character forms a connecting link between peat and ordinary coal, but it is not classed with true coals. The term is sometimes restricted to those varieties presenting an appearance to woody tissue; another kind, in which the woody aspect is more or less obscure, being termed 'brown coal.' Classified according to external characters, lignites are divided into—(1) woody or fibrous brown coal, with the form and structure of wood; (2) earthy lignite, compact and easily rubbed into a powder; (3) common brown coal, with the woody structure indistinct, possessing a slaty cleavage, and always black or dark brown in colour; (4) bituminous lignite or 'pitch coal' (*pechkohle, glanzkohle*), having a conchoidal fracture, pitch-black in colour, and frequently resembling coal, and sometimes even anthracite.

Lignites frequently contain fragments of leaves, bark, tissues, spores, macrospores, and pollen grains, all in an advanced stage of decomposition. They were formed in shallow waters in which infusoria could live, and in which fungi and bacteria were abundant.

Like peats, the chemical composition of lignites varies. The carbon percentage ranges between 60 and 75 per cent., that of hydrogen is about 5·0 per cent., and the oxygen and nitrogen between 20 and 35 per cent., calculated on the ash-free basis. A lignite from Germany shows percentages of: Carbon, 57·28; hydrogen, 6·03; oxygen and nitrogen, 36·16; ash, 0·59; that of a brown coal percentages of: Carbon, 61·20; hydrogen, 5·17; oxygen and nitrogen, 21·28; ash, 12·35.

Lignites are chiefly met with in the Tertiary formation, and form an important source of fuel on the Continent and in North America. In some districts they are the only source of fossil fuel. Many of the deposits on the Continent are mined by open-cast workings, and around Cologne one seam averages 100 feet in thickness and sometimes reaches a thickness of 300 feet. Tests conducted in the United States of America show that 'gas of a high quality can be obtained from the lignites of that country in North Dakota and Texas, and that one ton of lignite used in a gas-producer plant gives as much power as best Pennsylvanian or West Virginian bituminous coals used under boilers.' In Russia the Blatter Kohle and Papier Kohle have been regarded as

lignites of Lower Carboniferous age, but are more frequently referred to the bogheads and Torbanites.

Thin and local layers and pockets of lignite are occasionally found in beds of Eocene age in the south and east of England, but the only occurrence of any account is that of Bovey Tracey, south-west of Exeter, in strata of Tertiary age. Owing to its giving out a disagreeable odour when burnt it is not much used as a fuel, but attempts have been made recently to use it for the extraction of oil and mineral wax. Some of the carbonaceous beds reach a thickness of nearly 50 feet; but the lignite is in beds from 1 to 4 feet in thickness. Analyses give: Carbon, 66·31; hydrogen, 5·63; oxygen, 22·86; nitrogen, 0·57; sulphur, 2·36; ash, 2·27. Analyses so far made do not warrant that the lignite could be profitably extracted as a source of montan wax.

Cannel.—In association with true coal, or else existing in separate beds, dull-black, lustreless, carbonaceous substances, breaking with a conchoidal or splinty fracture, are often met with. The variety breaking with a conchoidal fracture and lighting readily with the emission of a smoky candle-light flame is called 'cannel.' It is frequently capable of taking a fine polish, and, like the jet of the Yorkshire Lias, is made into ornaments. When interstratified with coal it is often named 'splint coal,' 'stone coal,' 'parrot,' 'lantern,' 'cornish'; when with shale it is called 'hoo-cannel,' 'blend,' 'rattler,' 'jacks,' 'rattler jacks,' 'peel,' 'drub.' From the smell when burning it is known as 'horn coal.' Cannel always occurs as small lenticles or in lenticular beds, generally a few inches thick, and only exceptionally met with in beds over 2 feet in thickness. It was evidently laid down in water, which was very little subject to disturbance, and in which fish and other animals must have lived, since their remains are frequently found in an almost perfect state of preservation in the cannel.

Best Wigan cannel contains percentages of: Carbon, 80·07; hydrogen, 5·53; oxygen and nitrogen, 10·20; ash, 2·70. Such high-class cannels are rare, and the common kind generally contains a very much higher percentage of ash—sometimes as high as 80 per cent.—rendering it commercially unprofitable. Sulphur is usually present. Cannel and its allies were formerly an important source of gas for increasing the luminosity of gases obtained from bituminous coals; and is still used locally for this purpose. It was also much used for the distillation of oil, and has been lately

the subject of experiment. From a ton of 'bastard cannel,' as the inferior kinds are called, the products obtained in a specially designed apparatus included: Pitch, 100 pounds; semi-solid wax, 50 pounds; soda-soluble oil, 4 gallons; phenolic ethers, $1\frac{1}{2}$ gallons; hydrocarbon oil, $6\frac{1}{2}$ gallons. The total yield of ammonium sulphate was 35 to 40 pounds per ton, and 6,000 cubic feet the yield of gas.

The origin of cannel is a subject of much dispute. Some cannels are rich in the fructifications of cryptogams, chiefly the spores of Lycopods; others, again, under the microscope appear structureless, but even then it is believed that the substance is largely built up of spores. It is generally accepted that cannel was formed in still, carbonaceous waters. Under such circumstances at the present day a gelatinous mass or slime accumulates at the bottom, consisting of both animal and vegetable matter, and in this material the least destructible organs, such as spores, become embedded. The gelatinous substance is called 'sapropel.' When occurring in a fossil state in Palæozoic strata, the term 'sapranthrakon' is used by some Continental writers, and the term 'saprodil' when it is found in the Tertiary formations.

Boghead Coal.—Boghead coal, or 'torbanite,' as it is sometimes called, from its occurrence at Torbane Hill, Linlithgowshire, is regarded by some authorities as a variety of cannel coal, but others dispute its right to be included in the coal series; indeed, such a dispute resulted in a prolonged lawsuit last century. For several years the Torbane Hill mineral yielded the raw material for the extraction of oil, and some of it was exported for distillation to America and the Continent. Its percentage proximate composition consists of: Volatile hydrocarbons, 61·42; fixed carbon, 8·81; sulphur, 0·27; ash, 29·17; moisture, 0·60. The ultimate composition is: Carbon, 60 to 65 per cent.; hydrogen, 7·5 to 9·0 per cent.; oxygen, 4·0 to 8·0 per cent.; nitrogen, 0·55 to 1·53 per cent.; ash, 19·75 to 20·32 per cent. The material is of a brown or nearly black colour, with a conchoidal fracture, and a yellow or fawn-coloured streak. It is a mass of structureless carbonaceous matter, mingled with the remains of *Sigillaria* and *Stigmaria* that occur throughout the bed. Near igneous intrusions it has been converted into a soft, sticky, brown substance. It was mined to the point of exhaustion, and though somewhat

similar carbonaceous materials occur at Methel, Capeldrae, Lesmahagow, and Rocksoles in Scotland, and associated with the Black Band Ironstones of North Staffordshire, none of these approach the original Torbanite in their yield of oil, which amounted to 90 gallons or less to 130 gallons per ton. In the process of distillation Torbanite left a residue, not of coke, as in the case of a true cannel and bituminous coal, but ash with a small proportion of carbon. The carbon compounds contained in Torbanite are not soluble in benzene, turpentine, carbon bisulphide, thus resembling those carbon compounds of coal, and not those of petroleum, resin, or true bitumen.

Under the microscope the bogheads of Autun and New South Wales, it has been declared, are seen to consist of aggregations of the oval and circular thalli of *Pila* and *Reinschia* (colonial algæ) in association with pollen grains of various carboniferous plants. But the identification of thalli has been denied by others, who regard them as the megaspores of vascular cryptogams, in which case bogheads resemble cannels in their organic origin, as they certainly approach them in their behaviour with chemical reagents.

Other combustible substances allied to Torbanite are: *Byerite*, a bituminous coal from the Middle Parks, Colorado; *Tasmanite*, a carbonaceous shale of a brown colour found on the River Mersey, in Tasmania, in a bed from 6 to 7 feet thick, and resembling the 'White Coal' of Tertiary age in Australia. The ash contents of both is very high—over 68 per cent. in the case of white coal. Combustible materials which have been mistaken for coal include: *Anthraxolite*, a coal-like substance of variable composition found in the older formations of Quebec and Ontario, and usually regarded as a form of inspissated petroleum; *Albertite*, similar in appearance to anthraxolite, but placed among the mineral asphalts. The carbonaceous deposit in the Laxey lead-mine, Isle of Man, is probably some form of one of these minerals.

Coal.—As popularly understood, coal includes the several varieties of fuel intermediate in physical appearance between brown coal and the stone-like or metallic-looking anthracite. Ordinary house coal presents bright surfaces that, however, soil the fingers, and breaks into more or less rectangular lumps. Generally the bright parts of coal are interleaved with dull layers (mother of coal). In many steam coals dull layers form a large proportion of the seam; others, as

in many best Welsh steam coals, resemble the more metallic looking anthracite.

Anthracite or Stone Coal is stone-like in appearance, having a semi-metallic lustre, and can be handled without soiling the fingers. True anthracites burn with a feebly luminous but smokeless flame, and are much less easily combustible than any other variety of coal. They are the least widely distributed of all the kinds of coal, the purest coming from South Wales and Pennsylvania. In greatly disturbed and folded regions, as in Pembrokeshire and North Devon, where the seams of anthracite have been subjected to great pressure, the coal has been crushed into a fine powder or natural slack, which is called 'culm.' When artificially compacted or kneaded with clay it forms a slowly burning fuel used in Devonshire and West Pembroke. In Devonshire the crushed powder has long been used as the basis of black paint.

Sampling Coal.—The value of an analysis of a coal seam depends in the first instance on the method adopted in the selection of the samples. This is evidently of the utmost importance, and frequently falls under the care of a geologist or pioneer.

A seam of coal is generally made up of layers possessing different properties and value. Some layers, especially of abnormally thick seams, are worthless as fuel. A small piece selected from one thin layer will therefore give very misleading results in the analysis of a thick seam. Usually in a coal mine a sample of about 20 to 30 pounds in weight is taken from each of at least two of the working faces situated as far apart from each other as possible. To obtain this amount a cut about 3 inches wide is made from roof to floor across the seam, neglecting the bands not sent to market, but including those taken out and sold with the coal. If a sample of 20 pounds is too bulky for transport, it is first reduced at the mine by breaking up all the material of the sample into small pieces, thoroughly mixing them, and making four portions of the broken material; and then taking alternate quarters and again mixing and halving. This process, which is called quartering, is continued until a convenient amount is obtained. Whenever possible this breaking, mixing, and quartering should be left to the analyst.

Analyses of Coal.—The chemist generally furnishes two analyses of coal: one called the 'proximate' and the other the

'ultimate' analysis. A proximate analysis furnishes percentages of volatile combustible matter, fixed carbon, ash, sulphur, and moisture. An estimate of the yield of coke per ton is usually given, together with its physical character, and the percentages of carbon, sulphur, and ash contained in the coke. This form is the general trade analysis, and is not sufficiently reliable as a basis for classificatory purposes. In a good ultimate analysis the carbon, hydrogen, oxygen, and nitrogen are expressed in percentages calculated for the 'pure coal' (*i.e.*, after deduction for moisture, ash, and combustible matter). The percentage of volatile matter is calculated on the coal exclusive of moisture and ash. The ash is given in percentages of the dry coal. The ultimate analysis is required if the coal is to be carbonized or gasified in producers under ammonia recovery conditions.

Classification of Coals.—Coals are classified according to their suitability for certain purposes, or according to their chemical composition. In South Wales the coals are classed for general sale purposes into: (1) Bituminous coals, to include house, gas, coking, and manufacturing coals; (2) semi-bituminous or second-class steam coal, applicable for stationary engines, locomotives, and bunkering purposes; (3) 'first-class steam,' and seams of a similar character for coal supplied to the Admiralty; (4) 'steam' and 'anthracite,' used for steam-raising, malting, lime-burning, gas-power, hop-drying, and for domestic purposes. The marketable value of a coal depends to a great extent on the amount, chemical composition, and fusibility of the ash, and its liability to attack the material with which it comes in contact. Sulphur, always deleterious, frequently renders a seam worthless; and even in small quantities often makes a seam useless for many metallurgical processes. Phosphorus is always present in coal, though in small and varying quantities. Arsenic, commonly contained in the 'brasses' or iron pyrites of coals, is a dangerous constituent when the coal is used for malting, and the arsenic rises to $\frac{1}{15}$ of a grain per pound.

Humic coal has been suggested as an equivalent term for bituminous coal, since bitumen is never present in any coal.

Best coke contains over 90 per cent. of carbon and less than 9 per cent. of ash. Best gas coal yields on a dry, ashless fuel 30 to 38 per cent. of volatile matter; best coking coal from 20 to 30 per cent., and best steam coal less than 20 per cent.

Various chemical classifications have been suggested, based on (1) percentage of carbon and hydrogen, calculated on pure coal; (2) the relative proportion of carbon to hydrogen; (3) the relative proportion of coke to volatile matter—fuel ratio—but is unsatisfactory except for anthracite and semi-anthracite coals; (4) on the fixed carbon for the anthracites to the semi-bituminous coals, and on fixed carbon and total carbon for the bituminous and lignitious coals. The fuels previously mentioned are classed according to the fixed carbon basis into : Anthracite, with fixed carbon, over 93; semi-anthracite, fixed carbon, 83 to 93; semi-bituminous, fixed carbon, 73 to 83; high-grade bituminous, fixed carbon, 48 to 73, total carbon, 82 to 88; low-grade bituminous, fixed carbon, 48 to 73, total carbon, 76·2 to 82; cannel, fixed carbon, 35 to 48, total carbon, 76·2 to 88; lignite, fixed carbon, 30 to 55, total carbon, 65 to 73·6.

Commercial Valuations.—The properties of a coal for general purposes depend upon its friability, specific gravity, and calorific power. Friability varies according to origin and composition—lignites are commonly very friable, while anthracites are stony—but to a great extent on the earth-pressure to which coals have been subjected. It is an important factor where the coal is transported and transhipped. Briquetting such friable coals is a common practice in France, and it is stated that many of the Kent coals form suitable briquettes. Many friable coals, however, will not briquette without the admixture of other material. In America experiments have shown that soft pitch added to the slack of Arkansas coal and briquetted by English machines yield briquettes which stand much handling when cold, and form a high-grade fuel.

The specific gravity of coal is of importance where the storage space is limited, as on railway engines, and in ships' bunkers. In anthracites the specific gravity varies from 1·33 to 1·48, and in bituminous coals from 1·26 to 1·31.

The heating power of coal depends chiefly upon the amount of carbon and hydrogen.

To ascertain the calorific value of a coal, a known weight is burnt under the most favourable circumstances so as to insure complete combustion. The unit of heat adopted is either the calorie (gramme degree)—*i.e.*, the amount of heat required to raise 1 gramme of water 1° Centigrade —or that of the British thermal unit, which expresses the amount of heat needed to raise 1 pound of water

1° Fahrenheit. The calorific power, therefore, expresses the number of units of heat produced by the combustion of unit weight of fuel. The calorific value expressed in British thermal units per pound may be converted into calories per gramme by multiplying by five and dividing by nine. A pound of ordinary British coal gives out during combustion about 14,000 British units of heat. A good Welsh steam coal will give out 15,000 British units of heat.

CHAPTER II

COAL AS A ROCK

From considering coal as a mineral substance we have now to study it as a rock in its relation to other rocks.

In whatever region of the globe or in whatever formation coal occurs, it is always found in connection with sediments that have been laid down under water, but whose lithological characters and fossil contents betray the close proximity of land.

Among these sediments coal forms a distinct layer or bed, varying from a few inches up to as much as 300 feet in thickness. Not infrequently it is found in beds from 4 to 5 feet thick, and this is regarded as a most convenient occurrence for profitable working. Coals under a foot thick are rarely mined, and seams over 10 feet thick are costly and wasteful to obtain.

Coal-bearing strata frequently much exceed 5,000 feet in thickness, and throughout this great mass of sediments the seams of coal occur on different horizons. Usually several seams are grouped together; others, again, are separated by several hundred feet of barren strata. In all cases the coal forms only a small proportion of the sediments, and the united thickness of the different seams rarely amounts to more than a hundred feet, and is usually less.

Coal.—The 'floor,' or bed of rock on which the coal rests, is commonly a white or pale grey clay—'underclay,' 'seat-stone,' 'warrant,' 'spavin'—but not infrequently consists of shale, of sandstone, of conglomerate (Garw Coal, Beaufort, South Wales); occasionally of limestone (Fifeshire), of volcanic rocks (Central France), or of granite and schist. Underclays vary in thickness from a mere film up to 10 feet or more. In deep workings, where the pressure due to the weight of the overlying strata is very great, the nature of the floor becomes of considerable importance, as when of clay or soft shale the floor swells up and increases the difficulty of keeping open the underground workings, so that

packings of hard rock have to be introduced to prevent the floor encroaching on the roof.

The 'roof,' or bed of rock immediately overlying a seam, is usually shale or sandstone, but it may consist of a conglomerate, a soft clay, or a limestone. Igneous rocks sometimes form the roof and floor of a coal-seam, but this occurrence can be regarded as exceptional. Both the nature of the roof and of the floor of the same coal often change rapidly. A sandstone roof may pass laterally into one of shale or clay, and the floor that at one spot is a sandstone or shale become in a short distance clay and seat-earth. This variation in the character of the roof, as well as that of the floor, affects the commercial value of a seam, a good roof rendering it safer and less costly to work the coal. Cases occur where a bad roof has made it unprofitable to work an excellent seam of coal.

The 'seam,' as a bed of coal is commonly called, though the term 'vein' is sometimes (South Wales) erroneously used, may be confined to a very limited area, or, as in the case of the Pittsburg Seam of the Appalachian Coalfield, it may extend over an area exceeding 14,000 square miles. In South Wales several seams, though under different names, have been traced along the entire length of the coalfield; and in the eastern midland counties of England individual seams have been followed almost uninterruptedly from the Trent near Nottingham to the Humber. Individual seams occurring in groups seldom maintain the same distance apart for more than a limited area, but it frequently happens that the highest and lowest seams of a group remain parallel for considerable distances.

A seam of coal sometimes retains the same character over wide areas, any particular seam being a bituminous, semi-bituminous, or steam coal throughout its lateral extension and for its entire thickness. Usually, however, a seam is of a composite character, and is built up of different qualities arranged in separate layers that occur in one order in one place, and in a somewhat different order in another place, though some seams preserve the same arrangement in the composition of the layers over considerable areas.

Some seams, again, consist of good marketable coal from top to bottom, and retain this character over several square miles; then, locally, bands of clay, shale, or sandstone become intercalated, until, finally, these bands become abundant and the seam passes into a worthless mixture of

foreign material and thin layers of coal. As a rule the partings occur irregularly, but in some cases the introduction of 'dirt' layers takes place in a definite direction. In the description of many foreign coals the numerous intercalated thin bands of shale or other material are often included in the total thickness of a seam, and its importance is in this way much exaggerated. Many of the seams in South Africa, for instance, are said to attain a thickness of over 20 feet, but in most cases only a comparatively small portion consists of marketable coal occurring in layers a few inches thick.

Local inclusions of lenticles of sandstone, shale, or other foreign material, in a seam of coal are common, and are termed by the miner 'horses,' 'washouts,' or 'rock faults,' though a 'horse' is distinct in its origin from a 'washout.' Sometimes a ridge of sandstone or shale rises up through the floor of a coal, which then ends off abruptly, the foreign substance being termed a 'roll' or 'swell.' Such lenticular masses of sandstone and shale may entirely replace a seam, as in many 'washouts,' or only a portion of the seam, as in the case of 'horses,' 'rolls,' or 'swells.' 'Washouts' often extend over several acres and in more or less defined channels, extending several miles. 'Horses' and 'swells' are local phenomena, and are common to many districts, and are well illustrated in the Thick Coal areas of South Staffordshire and Warwickshire.

One of the most extensive forms of 'washout' in this country is that of the 'Symon Fault' of the Coalbrookdale Coalfield, in which a mass of barren sandstones and shales fills up an old channel cut into the coal-bearing strata. In its adventitious occurrence and its high ash contents cannel coal behaves as a 'horse.' In all cases it occurs as lenticles, forming part of a composite seam, and, like a dirt parting, appears irregularly and as a lenticle or wedge, and rarely showing a definite direction of development.

Coal-Measures.—Seams of coal, with their roofs and floors, form a fractional part of the strata in which coals occur. The term 'Coal-measures' is often technically applied to strata of any geological formation carrying coal in sufficient quantity to be worth working. In England, and generally in Scotland, the term is confined to a definite part of the Carboniferous System, whether it contains coal in workable quantity or not.

The associated sediments belonging to the Coal-

measures consist of different classes of rocks, from which only those of deep-sea origin are excluded. In Scotland igneous rocks are common, but are mainly, though not entirely, intrusive, and in England are all of an intrusive character. In Scotland volcanic rocks are abundantly developed on several horizons below the Coal-measures among coal-bearing strata of Lower Carboniferous age.

The sediments intimately associated with coal-seams consist of: (*a*) sandstones; (*b*) shales and clays; (*c*) limestones; (*d*) ironstones.

Sandstones.—In many mining records these are called 'rock' or 'post' in the North of England. The prevailing character is one of great variability in thickness and composition. Coal-measure sandstones occur, not as regular beds, but as wedge-shaped masses, commencing suddenly, rapidly swelling out, and as quickly dying away. In composition they vary from a fine-grained, laminated rock to a coarse, thick-bedded sandstone, with the coarse types developed towards the bottom of a local sequence. By the addition of shaly material in grains or layers sandstones lose their individuality and pass into sandy shales ('fakes' in Scotland, 'clift' in South Wales), or into a bed made up of sandstone and shale in alternate layers. When closely associated with seams of coal, the sandstones are universally grey or yellow in colour: red sandstones, in which the colouring matter is original, are scarcely ever found in close proximity to coal, and it is observed that in a lateral change from grey to red coal-seams deteriorate in thickness or entirely disappear in the Carboniferous formation. It is also a common experience that red strata of later Palæozoic, Mesozoic, and Tertiary ages are not only remarkably barren of organic remains, but are equally destitute of coal. Although an individual bed of sandstone varies greatly and rapidly both in thickness and composition, certain groups of sandstones in most coalfields occupy definite horizons and extend over several square miles of country. For instance, in the coalfields of South Wales and Bristol, the Pennant Sandstone, consisting of a great thickness of sandstone with subordinate bands of shale, separates a lower coal-bearing series from an upper coal series, and can be traced continuously over Monmouthshire and Glamorganshire. Sandstones of a more local development are frequently used as an index of horizon, though, unless, as is rarely the case, they possess very distinctive characters,

sandstones of one horizon are very apt to be mistaken for those on another level.

Shales.—This term—'blaes' in Scotland—is applied to laminated rocks in which argillaceous material forms an essential constituent. Unlike the sandstones, the shales occur in more or less regular beds occupying definite positions in a Coal-measure sequence, but unless containing special fossils remain unnamed. By the addition of sandy material these rocks graduate upwards and laterally into sandy shales, though the change is often abrupt.

The term 'shale' is usually restricted to a finely laminated argillaceous rock. For one in which the lamination is indistinct the term 'clay,' 'fireclay,' or 'marl' is given, the name referring to its physical character without particular regard to its composition. Technically speaking, marl contains much calcareous matter, and the so-called marls of the Coal-measures are more truly clays with a composition consisting of: Silica, 49·44; alumina, 34·26; sesquioxide of iron, 7·74; lime, 1·48; magnesia, 5·14; water, 1·94. In this country the laminated varieties are known to the miner as 'binds,' and when much sandy material is present they are called 'stony binds' or 'rock binds.' Unlaminated varieties are commonly known as 'soft binds.' When a high percentage of carbonaceous matter is present the rock is termed a 'bass' or 'batt.' Such highly carbonaceous shales, however, seldom exceed a few feet in thickness, and are closely associated with seams of coal. They frequently contain oil-yielding compounds, and pass laterally into beds of bastard cannel rich in kerogen, as in the Torbanite of Scotland and the oil shales of North Staffordshire.

Coal-measure shales vary in colour from light grey to black, and at outcrop are frequently bleached white and lose all traces of lamination. Among the lighter-coloured varieties encountered in sinking shafts or in borings, one, of a light blue colour and with a greasy appearance, to which the term 'soapy bind' is applied, frequently shows its origin by containing Lingula and other marine organisms. Red shales and clays are not common in the coal-bearing part of a Coal-measure sequence, but generally accompany red sandstones, and, like these, were commonly deposited during the closing stages of the Coal-measure period.

No term, perhaps, is more loosely applied than that of 'fireclay' or 'clunch.' It is indiscriminately given to any

pale-coloured clay containing rootlets, or what look like rootlets, of fossil plants, without regard to its composition. Technically, a fireclay of economic value consists of hydrous aluminium silicates with a varying but small percentage of iron, magnesia, lime, and alkalies. A 'rational' analysis of a good fireclay shows percentages of: Clay substance, 70 to 90; quartz, 7 to 30; felspar, 0·5 to 2. The clay substance is very similar to kaolin in its chemical, physical, and mineralogical characters. By a decrease in the amount of clay material and its replacement by a fine silt, fireclays pass into ganister. The most siliceous form is an intensely hard, close-grained, compact stone, formerly extensively quarried round Sheffield for road-metal, but now highly prized as furnishing the chief constituent of a high-class refractory brick used on a large scale at the steel works. In this rock the silica often approaches 100 per cent., and is rarely lower than 90 per cent.

Before leaving this class of sediment it should be noted that fossils, whether of plants or of animals, are more frequently met with in the shale bands. Owing to the quick way in which the shales weather down into clay, it is only in fresh material that the fossils are preserved. Unless, then, an opportunity is taken to examine fresh material fossils are seldom found, and it is due in great part to this cause that the Coal-measures have been regarded as particularly unfossiliferous.

Limestones.—These are not of such general occurrence among coal-bearing strata as either sandstones, shales, or clays, and are seldom found in actual contact with a seam of coal. In the Carboniferous formation of Great Britain, for instance, the coals in the lower or limestone division are restricted to the northern counties and Scotland, but beds of sandstone and shale are in this case interstratified with the limestone bands, which seldom exceed 10 feet in thickness. In the centre of England and in the south-west, where the limestone is massive and rich in corals, workable seams of coal are unknown, though coal occasionally occurs in thin layers or pockets. Limestones, however, are more general among the coal-bearing strata of Carboniferous age in Russia, and in the Cretaceous formation of North America coals are found with a marine limestone forming both roof and floor. Thin beds of earthy limestone are met with at definite horizons in the Coal-measures of Central England.

Ironstones.—Coal-bearing strata generally contain nodules

and bands of ironstone interstratified with the shales and clays, and sometimes accompanied by a coal. Laminated bands of clay-ironstone, containing a high percentage of carbonaceous matter, are called 'Black Band Ironstones,' and form valuable beds in North Staffordshire and Scotland. These laminated ores are generally rich in fossil plants and shells. In many cases the ferrous carbonates of Black Band ironstones have replaced carbonates of lime, and not infrequently pass laterally into impure limestones. Nodules of clay-ironstone occur in nearly all coal-bearing shales and clays, whether of marine, fresh-water, or estuarine origin. The nodules are either flat, oval, or irregular in shape, sometimes occurring in layers, at others irregularly distributed. They frequently enclose a fragment of a fern or a shell, and other fossils in a perfect state of preservation.

Conditions.—The sedimentary rocks associated with coal-bearing strata have been deposited under two very different physical conditions. In one they have been laid down in the comparatively tranquil waters of lakes, and in the other case in the agitated waters of estuaries and along sea-borders. In lakes the sediment discharged by streams and rivers quickly sinks to the bottom, and is only roughly sorted out into stratified layers, whereas material under the influence of tidal currents is spread out into wider and more definite layers. This difference in the arrangement of the sediments is very conspicuous among the coal-formations of the world. In England and Northern France the Coal-measures were deposited in estuaries or along a maritime border; in Central France the lacustrine origin of the isolated basins is a well-attested fact. The comparative regularity of the sequence in the first two areas is in sharp contrast with the coarse-grained, extremely false-bedded, and roughly stratified sediments of the Commentry Coalfield on the northern margin of the ancient central plateaux of France.

The arenaceous sediments of coal-bearing formations were not only distributed very irregularly, but were deposited at different rates. Most of the Carboniferous sandstones, it is generally accepted, were laid down with great rapidity, and according to the estimate of Sorby, some of the sandbanks advanced at a rate of one inch per minute. Shales and clays, on the other hand, indicate a slowing down in the rate of deposition. This affords one solution of the very great variability met with in the thickness of strata separating two seams of coal in closely contiguous areas. In very

many cases this is due to the intercalation, or swelling out, of a bed of sandstone as seen in the marked differences in level between two well-defined seams in the sections of neighbouring collieries, and sometimes even in those of two shafts.

In many of the coalfields of Europe, Asia, and America, the close of the Carboniferous period is marked by a particular class of sediment, consisting of red sandstones, shales, and clays, often amounting to hundreds of feet in thickness. Thin bands, a foot or two thick, of creamy-white and black limestones, but invariably fine-grained, occur at intervals. With the exception of a few plants in the shales, of occasional reptilian remains in the sandstones, and of small organisms (Entomostraca) in the limestones, these rocks are alike poor in coal and organic remains. It is impossible to escape the conviction that these strata were laid down under very different conditions to those under which the coal-bearing rocks were deposited. The probable solution is to be found in the closing up of the outlets and the formation of a closed basin into which the waters of the period were discharged. Under these conditions, each grain of sand and every pellicle of clay became coated with a film of iron oxide (Fe_2O_3) precipitated from the stagnant waters. The water containing the iron salts also held lime in solution, which was precipitated as evaporation proceeded, to give rise to the thin ferruginous limestone bands. These are, therefore, to a great extent of inorganic and not of organic origin, such as the limestone beds of the Carboniferous Limestone Series of the North of England. It is interesting also to note that the closing phases of the coal-bearing strata of later formations are generally of a red colour.

Associated Igneous Rocks.—Sedimentary rocks associated with coal-bearing strata are arranged in layers, one bed above the other; igneous rocks, on the contrary, for the most part cross the stratified sediments at varying but usually high angles. This occurrence is known as a dyke. Igneous material also occurs in masses apparently interstratified with the sediments, and is occasionally contemporaneous with the deposition of the coal-bearing sediments. When a layer of igneous material is found lying parallel with the bedding of the sedimentary strata, it may either have intruded itself along the bedding planes or have been poured out over the layers of sandstone, shale, or coal at

the time they were in process of formation. In the former case the igneous rock will bake and harden the beds above and below; in the latter case only the bed beneath will have been affected. In both cases the alteration of a sandstone or a shale is usually extremely slight, and is often confined to the actual contact zone. Even in the case of the molten matter coming into contact with a seam of coal the change in the character of the coal is often slight. On the other hand, dark-coloured igneous rocks, such as dolerites, often become white when in contact with a coal. In the Hunter Coalfield, and in parts of South Africa, extensive areas of coal are completely ruined; on the contrary, in the western coalfield of New South Wales the coals remain unaltered to within a few feet of a huge lacollitic mass of a rock belonging to the nepheline-syenite group. The chemical alteration consists in an enrichment of carbon, thereby changing a bituminous into a semi-bituminous or even anthracite coal. Thus the unburnt Upper Drumgray Coal of the Lanarkshire Coalfield shows an analysis of: Fixed carbonaceous matter, 48·91; volatile matter, 26·52; moisture, 9·24; ash, 5·33; and that of the burnt coal the following analysis: Fixed carbonaceous matter, 48·92; volatile matter, 23·32; moisture, 1·98; ash, 25·78. This gives a fuel ratio of 1·339 for the unaltered coal, and of 2·10 for the burnt coal. Coals near intrusions also have a coke-like appearance (*senseki* of the Japanese) and a columnar structure.

CHAPTER III

FORMATION AND ORIGIN

It is now universally admitted that the several varieties of coal have resulted from the alteration of vegetable matter, but very divergent opinions are still held as to the method of its accumulation and conversion into coal.

Extensive and often thick deposits of vegetable material are to be found in peat-bogs and swamps, or they result from the accumulation of drifted wood carried from the land and laid down under water at the mouths of large rivers. In this country and in America, due mainly to the teaching of Logan, de la Beche, and Principal Dawson, a coal-seam is considered to represent an original peat-bog; on the Continent the opinion is often held that the majority of coal-seams have resulted from drifted material. Two opposing views, known as the 'growth *in situ*' and 'drift' origin, are in consequence held, though there is at present a tendency for some geologists in this country to regard many of the British seams as having been formed out of drifted material. The supporters of either view do not suppose that the vegetation accumulated in deep water on the one hand, or on elevated ground on the other. Both theories start with a low-lying maritime morass or a peat-bog, but, according to one view, the coal-bed and its seat-earth represent the actual site of the swamp, while, according to the other view, the vegetable débris was floated out from the swamp into the neighbouring still lagoons. Thick seams of coal containing numerous partings of shale, like those of India, Africa, and Australia, have always been considered to have originated from vegetable material drifted out into inland lakes.

The essential factors which either theory must satisfactorily account for are: (1) The great areas often occupied by individual seams; (2) the absence of foreign material, such as sand, etc., from the coals; (3) the maintenance of a uniform thickness, often by a thin seam, over considerable

areas; (4) the behaviour of a coal-seam as a sedimentary rock amidst rocks whose sedimentary origin is unquestionable. By those upholding the 'growth *in situ*' theory stress is chiefly laid on the purity of many of the seams, and the frequent, but by no means universal, occurrence of an underclay (fireclay), considered to be an old soil beneath the seam, and on the presence of vertical stems of fossil trees in the rock forming the roof of a coal with their roots penetrating the underclays. 'Seat-earths' are, however, often absent, and the seam lies directly on sandstone, conglomerate, or shale, without a trace of rootlets, while it is not certain that the 'seat-earths' represent ancient soils. A strict analysis of the position of the trunks of trees in the so-called 'fossil forests' shows a greater percentage of prostrate or inclined trunks than those having a vertical position.

In the case of numerous and closely contiguous seams, separated by marine sediments, the 'growth *in situ*' theory demands rapid and frequent oscillatory earth movements. First a land surface, with the formation of peat, then its depression and burial, these operations being many times repeated.

The supporters of the 'drift' origin of the woody material base their chief claim on the behaviour of a coal-seam as a sedimentary rock. Many seams made up of layers of coal with partings of dirt, shale, clay, or sandstone, varying from a mere film to several feet in thickness, pass laterally into beds of almost pure coal. According to this view, therefore, a seam of nearly pure coal indicates a spot to which only the lightest and finest material had access. Coal-seams would be formed during intermittent, but downward, earth movements, during the formation of a depression which became consecutively filled with coarse material (sandstone), followed by finer sediments (shales and clays), and finally by drifted wood and plant débris—the lightest of all.

Thus, among marine coal-bearing strata an upward succession of limestone, sandstone, shale, clay, coal is frequently observed, and in estuarine and fresh-water coals a sequence of sandstone, shale, clay, coal is of common occurrence.

The thickness of individual seams does not receive a satisfactory solution from the 'growth *in situ*' theory. It is calculated that it takes 10 feet of peat to form 1 foot of coal. The 30-foot coal of Dudley, therefore, would repre-

sent an original thickness of 300 feet of peat, which is far in excess of any peat at the present day. Again, for the 'drift' theory it is difficult to imagine an area to which only the lightest material had access for a period represented by 30 or more feet of coal, though there is reason to suppose that the transported decayed vegetation would reach its resting-place in a more or less condensed and incompressible state, so that 30 feet of pure coal, according to this view, need not represent many times its bulk of transported material. That the condensed vegetable pulp quickly hardened or passed into coal while the Coal-measures were still being deposited is shown by the not infrequent occurrence of angular or rounded pebbles of coal embedded in the Coal-measure sandstones of most coalfields; sometimes they have the structure of ordinary coal, with alternate bright and dull layers.

In regard to the vast areas, exceeding 12,000 square miles, over which one particular seam, such as the Pittsburg coal of America, extended, it is useless to speculate in face of our ignorance of the past conditions of climate, land configuration, and the growth and distribution of plant life; neither can we estimate over how great an area a deposit of one kind and of fairly uniform thickness could be laid down. The Rhætic bone bed and shales, among sediments, show that even a thin layer can, under favourable conditions, be almost uniformly laid down over an area of many thousands of square miles.

Both theories apply to the accumulation of vegetable matter as a whole. The most ardent advocate for the 'growth *in situ*' origin of coal admits that some seams, such as cannel coals, must be formed from drifted vegetation, while supporters of the 'drift' origin do not deny that some seams of coal are probably derived from the conversion of vegetation *in situ*.

Conversion.—The varieties of coal given in Chapter I. will be seen to differ from each other in the relative proportion of carbon to hydrogen and carbon to oxygen. In lignite the hydrogen and oxygen ratios are relatively high; in some bogheads we find a total elimination of hydrogen; and in graphite, the final stage in the conversion, a total elimination of both hydrogen and oxygen.

The relative proportions of hydrogen and oxygen present in the different varieties of coal are more clearly brought out if the amount of carbon is taken as constant, and the

proportion of the other constituents increased in the same ratio. This will be understood from the following table:

	Carbon.	*Hydrogen.*	*Oxygen and Nitrogen.*
Wood	100	12·3	86·8
Peat	100	9·7	54·7
Lignite	100	8·3	40·0
Brown coal	100	7·4	29·7
Coal	100	6·4	13·4
Anthracite	100	2·6	2·3

The increase in weight due to the conversion of wood into coal is shown by 1 cubic foot of wood weighing 30 pounds, and 1 cubit foot of anthracite weighing 90 pounds.

It is usual to consider that all coal, from the lignitic to the graphitic varieties, once existed in a state of peat, and that the subsequent alteration of the only partly decayed vegetable matter proceeded by successive stages long subsequent to burial. Recent researches, however, more especially by M. Renault, indicate that very different degrees of alteration can be effected by biological action prior to entombment, while the subsequent mechanical and physical changes may be relatively trifling, and many palæobotanists doubt if peat, lignite, coal, and anthracite indicate a succeeding series in the process of coalification.

The conversion of once living vegetable matter into the mineral coal can be considered under two headings: (1) Changes prior to burial beneath sediments; and (2) changes subsequent to entombment.

The chief constituent of plants consists of some multiple of cellulose ($C_6H_{10}O_5$) with some nitrogen. Protoplasm, the living gelatinous substance, forms only a small portion, and perishes at death. In addition, there is a small percentage of inorganic salts of iron, potash, silica, and sulphur, seldom exceeding 3·5 per cent. The three main elements of vegetable tissue occur in the proportion of: Carbon, 50 to 58 per cent.; oxygen and nitrogen, 28 to 45 per cent.; and hydrogen. 5 to 7 per cent. This is true of the lowest plants —seaweeds, mosses, ferns, etc.—and of the highest—the flowering plants.

At the death of the plant, due largely to the action of anaerobic bacteria, the cellulose, under favourable conditions,

undergoes a partial deoxygenation and dehydrogenation, with the evolution of carbonic acid and marsh gas. The unused portions of the carbon and hydrogen of the cellulose enter into new combinations to form humic acid and hydrocarbons. The first is soluble in water; the latter consists of gaseous, liquid, or insoluble solid products. The chemical changes of cellulose into a bituminous coal are expressed by the equation, $4C_6H_{10}O_5 = C_9H_6O + 7CH_4 + 8CO_2 + 3H_2O$, where C_9H_6O represents a percentage composition of carbon, 83·1; hydrogen, 4·6; oxygen, 12·3.

In stagnant peat-bogs the humic products prevent further decay, and decomposition is arrested after a certain stage has been reached. In a free circulation of water, however, the decomposition, due to bacteriological fermentation, continues, certain parts of the plants being found to present different resistances to the action of bacteria. In the Blatter Kohle and Papier Kohle of Toula in Russia—of Lower Carboniferous age—for instance, the cuticles of *Bothrodendron* are found to have greatly resisted destruction. Epidermal cells, cuticles, grains of pollen, and spores are the most indestructible, but these ultimately become destroyed.

Prolonged maceration and bacterial action, therefore, result in an almost total obliteration of organic structure, and a loss in bulk amounting to from 10 to 30 per cent. of the original mass of vegetable débris. The successive stages are marked by the gradual elimination of hydrogen and oxygen, and a consequent increase in the carbon percentage. It is thus obvious that the chemical composition of the resulting organic pulp depends upon the stage at which decomposition was arrested. It is even conceivable that the organic pulp, having the approximate chemical composition of a lignitic, a bituminous, or even an anthracitic coal, may result, according to the stage at which the decomposition of the vegetable débris was arrested, though this is generally denied.

In a previous chapter the original nature of the vegetable débris, whether pollen grains, macrospores, leaves, cuticles, tissue, or bark, was shown to have played an important part in forming the composition of the resulting coal in its earlier stages. To this we may now add the resistance offered to bacteriological fermentation by the different parts of a plant. It will then be understood why one coal is almost structureless, another contains many leaf-stalks and cuticles,

and yet another is made of spores; and also why vegetable tissues, the most readily attacked of all parts of a plant by micro-organisms and fermentation, are so rarely preserved in coal. The easy decomposition of tissues forming the chief bulk of plants will also in some degree account for the fragmentary nature of the vegetable remains met with in coal. These do not necessarily imply that they are fragments torn away from the plants by wind and dropped into the morass, or floated out into the neighbouring lagoons, but are the remnants left of the more indestructible elements.

It is, however, more usually considered that the change from woody tissue into coal has for the most part taken place long subsequently to the burial beneath sediments, and no doubt many important changes have resulted from heat generated (1) under a thick covering of strata; (2) during pressure and folding; (3) by the intrusion of igneous material.

1. Where coal-seams lie at great depths or have once been covered by an immense thickness of strata, it is evident that the lower layers must have been subjected to a higher temperature than the upper seams. The amount of volatile matter, it is observed, decreases with the depth of the seam, the rate of change being more rapid in the bituminous than in the non-bituminous coals. This is known as Hilt's Law, and it is found to be applicable to many coalfields. There are, however, some notable exceptions. In the Saarbrucken coalfields the more bituminous seams are the deeper seated; and, again, in South Wales the bituminous coals along the southern outcrop have lain under as thick, or possibly a thicker, cover than the anthracite fields to the north. Neither can it be demonstrated that depth and pressure combined have resulted in an equal loss of volatile constituents, for in the northern coalfields of France lean, dry coals have been thrust over gas coals, both lying at considerable depths. Again, Hilt's Law will not account for the cannel coals of Russia, of Lower Carboniferous or later Devonian age, while pressure and depth both fail to give a satisfactory solution to the undisturbed anthracites of Carboniferous age in China. Many coals, it is observed, tend to become anthracitic on exposure to air at ordinary temperatures, and also lose some of their volatile constituents in the proximity of open faults or below a sandstone roof.

2. The alteration in the character of seams of coal affected

by heat evolved during folding and compression is illustrated in the Pennsylvanian and South Wales anthracite fields, both of which are situated in regions of intense folding. In South Wales the seams in the eastern and less disturbed area contain a much lower percentage of carbon, but are richer in volatile material than in the western, highly disturbed district. If the lines of anthracitization are followed from east to west, it is found that as a whole, though there are some exceptions, that the lower seams are the first to show a change, but that all the coals along the southern outcrop retain their bituminous character even when intensely folded. The American anthracite coals of Carboniferous age are confined to the folded Pennsylvanian basin, the bituminous varieties occurring in the less disturbed Appalachian and other coalfields. The same continent shows a phenomenon of Cretaceous and Tertiary coals becoming anthracitized on approaching the folded strata of the Rocky Mountains, and becoming converted into true anthracites in the most disturbed belts. In the intensely folded Alpine regions of Southern Europe the whole of the original volatile matter of some coals has been eliminated, and a bed of graphite formed. In Russia, also, the seams richest in carbon lie in the disturbed zone bordering the Ural Mountains, while those on the central plains of European Russia are in a lignitic state.

3. Bituminous coals of all ages, and in different parts of the world, become anthracitized when in contact with igneous rocks. The change, however, is usually local and sporadic. Moreover, coals in contact with igneous rocks contain a higher percentage of ash than those more remote, and very much less than those in which the cause of carbonification, though obscure, is certainly not due to heat derived from igneous intrusions, pressure, or depth.

It thus appears that terrestrial heat causes a certain amount of anthracitization, but the exceptions show that other considerations, such as original composition, must be taken into account. Indeed, if the chemical composition of a compound seam, such as the Barnsley Coal of Yorkshire and of many of the Scottish Carboniferous Limestone coals, be considered, it will be seen that under exactly similar conditions these seams consist partly of a highly bituminous coal and partly of an anthracitic coal.

CHAPTER IV

DISTRIBUTION

Distribution in Time.—The formations older than the Cambrian, and known as the Pre-Cambrian or Archæan, consist to a great extent of crystalline metamorphic rocks and those of volcanic and igneous origin. Coal, as might be expected, does not occur among strata of this character. Graphite, running in streaks and veins through igneous rocks, is evidently of inorganic origin. Among Pre-Cambrian shales and sandstones no definite signs of terrestrial plant remains have been discovered. Coal also does not occur in the older Palæozoic formations—Cambrian, Ordovician, Silurian—though black shales, sometimes carbonaceous, are frequently present. In many cases the sediments of the older Palæozoic rocks have been laid down in deep water, but coal-seams are not known even in the inshore and terrestrial deposits older than the Devonian period. Very little of the flora of this period has been preserved, so that it is impossible to say whether the absence of seams of coal is to be attributed to unfavourable conditions of preservation or to insufficient vegetation.

In the Old Red Sandstone (the lacustrine equivalent of the marine Devonian formation), ferns and other cryptogamic plants occur. Thin layers of coal appear, but are of rare occurrence until towards the close of the period, when in Russia several seams of inferior quality are interstratified between the Carboniferous Limestone and the marine Devonian.

From the Carboniferous period upwards to the Quaternary, each of the stratified formations, in one part of the world or another, contains beds of carbonaceous material, either as true coal or in the form of brown coal, lignite, and peat. The most valuable seams are always met with in the Carboniferous formation, and it is found that in countries where coals of various ages occur chief attention is given to the exploitation of the seams of Carboniferous age, even

when they are less accessible than the seams of inferior quality in the newer formations.

The Carboniferous strata often exceed 10,000 feet in thickness, and are divisible in Western Europe into a lower marine and upper estuarine or fresh-water part, in which

TABLE OF COAL-BEARING FORMATIONS.

Era (Group).	*Period (System).*	*Localities, Class of Fuel.*
Cainozoic or Tertiary.	Pleistocene.	Peat—northern hemisphere.
	Pliocene.	Peat.
	Miocene.	Lignites and lignitic coals of Central Europe.
	Oligocene.	Hungary, Austrian Alps, Moravia, Russia.
Mesozoic or Secondary.	Cretaceous.	N. Germany, Hungary, Rocky Mountains, Alaska, British Columbia, Manitoba, Japan, Borneo.
	Jurassic.	Yorkshire, Brora, Caucasus, Siberia, Japan, Alaska, Spitzbergen.
	Triassic.	S. Germany (Lettenkohle), United States, Tonkin, Yunnan, Japan.
Palæozoic or Primary.	Permian, Permo-Carboniferous.	Central France, South Africa, India, Australia, South America, Antarctic.
	Carboniferous.	True coals and anthracites in Northern Europe, North America, China.
	Devonian.	Russia.
	Silurian.	No fuels.
	Ordovician.	,,
	Cambrian.	,,
Eozoic.	Archæan.	,,

most of the coal-seams occur. As a rule the upper division occupies restricted areas in those coalfields in which both are developed. Some countries possess only the lower or marine part, and in Eastern Europe the upper and lower divisions contain marine sediments.

Succeeding the Carboniferous, the Permo-Carboniferous,

Permian, and Triassic formations yield the chief coals of the Southern Hemisphere. The coal-seams are frequently numerous, but many of them are usually of inferior quality, and none, except a few of Permo-Carboniferous age, are equal to the best Carboniferous coals. The flora is characteristic (Plate I.).

Coals of Jurassic, Cretaceous, and Tertiary ages are generally of low grade, soft, lignitic, and when of high grade owe their superiority to local circumstances. They are chiefly mined in those countries in which the Palæozoic coals are absent. Though occurring in beds, sometimes over 100 feet thick, Cretaceous and Tertiary coals are unevenly distributed.

The distribution of coal according to quantity has been estimated for each continent, and is as follows in millions of tons: Europe, 789,090; Asia, 1,279,586; Oceania, 170,408; Africa, 57,839; America, 5,111,528. According to the class of coal, the world's estimated supply of anthracitic coal is 496,846; of bituminous coal, 3,902,944; of sub-bituminous and brown coal, 7,397,553 millions of tons. In these estimates no allowance has been made for coal not mineable or for loss in mining.

Distribution in Space.—The superficial extent of the coal areas of the world has been estimated at 605,500 square miles, or in a ration of 1 : 110 of the land surface of the globe. About one-third belongs to formations newer than the Carboniferous. Coal is found in all latitudes between Spitzbergen and the Antarctic continent. It is of better quality as a whole in the Old World than in the New World; and those of the Northern Hemisphere are superior in quality to those of the Southern Hemisphere.

In Europe the chief coalfields in order of importance are those of Great Britain, Germany, Russia, with France and Belgium coming far behind in respect to output, but with the possibility of future large extensions, though at great depths.

Germany possesses coalfields of Carboniferous age yielding bituminous coals, and some of later age furnishing mainly lignitic coals. The chief Carboniferous coals are found in the Ruhr Basin, and occur in the Middle (Westphalian) Coal-measures which conformably succeed the Millstone Grit (Flotzleerer). Four groups are recognized in ascending sequence: (1) Mausegatt Group, with steam and house coals; (2) Sonnenschein Group, with fat coals; (3) Catherine

Group, with gas coals; and (4) Bismarck Group, furnishing gas and flaming coals. Upper Coal-measures (Stephanian),

FIG. 1.—THE CARBONIFEROUS COALFIELDS OF THE UNITED STATES.

containing fat and gas coals, are found in the Saarbrucken coalfield. Seams of coal also occur in the Lower Permian

(Kuseler bed) in strata containing Carbonicola and many Coal-measure plants.

Besides possessing an exposed coalfield, Belgium with Holland has a large concealed coalfield (Fig. 16). The Coal-measures consist of (1) a lower zone, containing several thin seams, which are thicker in Holland than in Belgium; (2) a middle sterile zone; (3) an upper zone, rich in coals containing a higher percentage of volatile matter than the seams of the lower zone. The cover consists of Upper Cretaceous, Eocene, Oligocene, Miocene, Pliocene, and Quaternary formations. These repose directly on Coal-measures in the part proved along the southern margin and over a wide area north and east of Maastricht. Towards the deeper parts of the basin red sandstone and marls of Permian and Triassic ages come in south of Maescyck, and have been proved in one boring to exceed 2,000 feet in thickness.

The northern coalfield of France is a continuation of that of Belgium. Traced westwards, the Coal-measures disappear under a cover of Cretaceous and later formations, but are known to extend to near the sea-border at Boulogne. The coalfield is noted for the number and intensity of the dislocations, and the duplication of the beds by overfolding and thrusting even on a grander scale than in South Wales.

North America now takes the first place in the annual output of coal, a supremacy long held by Great Britain. The Carboniferous formation covers vast areas in the United States, the Coal-measures alone occupying an exposed surface exceeding 230,000 square miles, though much consists of barren measures. In the western States the entire Carboniferous formation is marine; in the eastern States it is divisible into a lower (Mississippian) entirely marine stage, corresponding to the Carboniferous Limestone Series; and an upper (Pennsylvanian) stage, partly marine and partly estuarine, representing the lower and middle Coal-measures. A widespread unconformity separates the two stages. The coal occurs in the Pennsylvanian formation in the following coalfields: (1) Pennsylvanian Anthracite Region (484 square miles) (Fig. 2); (2) Appalachian Basin (70,000 square miles, with 70 per cent. workable coal); (3) Northern Interior Basin (7,500 square miles); (4) Eastern Interior Basin (46,000 square miles, of which 55 per cent. is productive); (5) Western Interior Coalfield, possibly over 90,000 square miles in area, but mainly con-

sisting of barren measures. Cretaceous coals lie in scattered basins between the 100th and 105th meridians, and Tertiary coals occur in small and widely separated regions between the 120th meridian and the Pacific Coast. Previous to

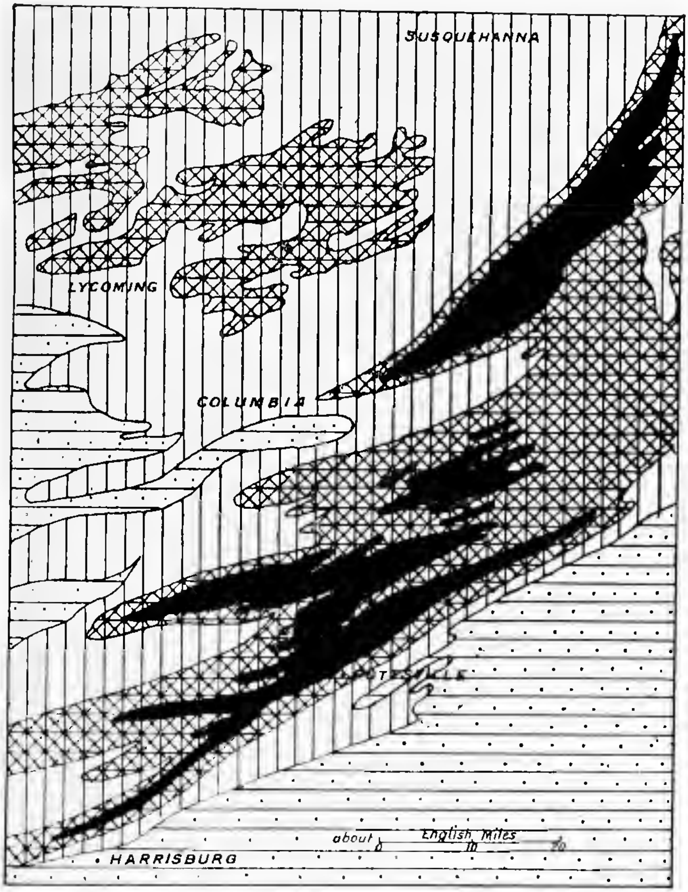


Fig. 2.—The Anthracite Coalfields of Pennsylvania.
Upper Carboniferous rocks in black; Lower Carboniferous rocks shown by lattice pattern; the remainder Devonian and Silurian.

1870 the production of anthracitic coal was a little more than half the production of the United States; that of soft coal is now over four times that of hard coal.

Canada, relatively to the United States, is poor in Carboniferous coals, but is rich in seams of Cretaceous and

Tertiary ages, occurring in British Columbia, Alberta, Saskatchewan, and Manitoba. The coals of the Cretaceous

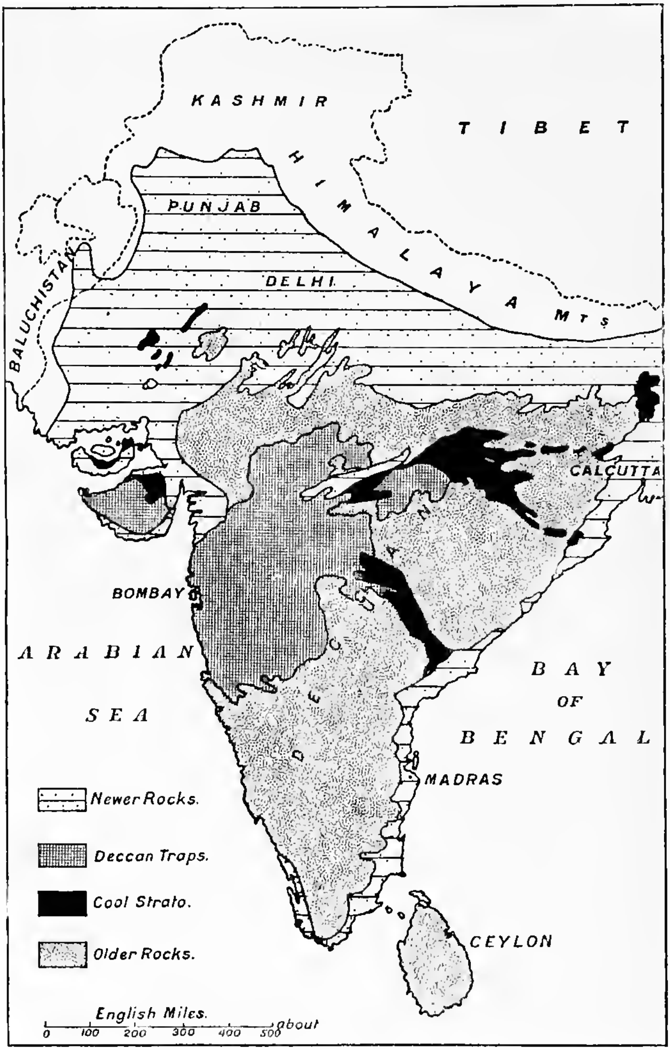


FIG. 3.—THE PERMO-CARBONIFEROUS COALFIELDS OF INDIA.

system occur in the Kootanay and Dakota divisions, and in the top part of the Montana division, the two coal-producing series being separated by the barren Colorado formation.

Estimated reserves of Canadian coals, given in classes of coal, in millions of tons are: anthracite, 400; anthracitic

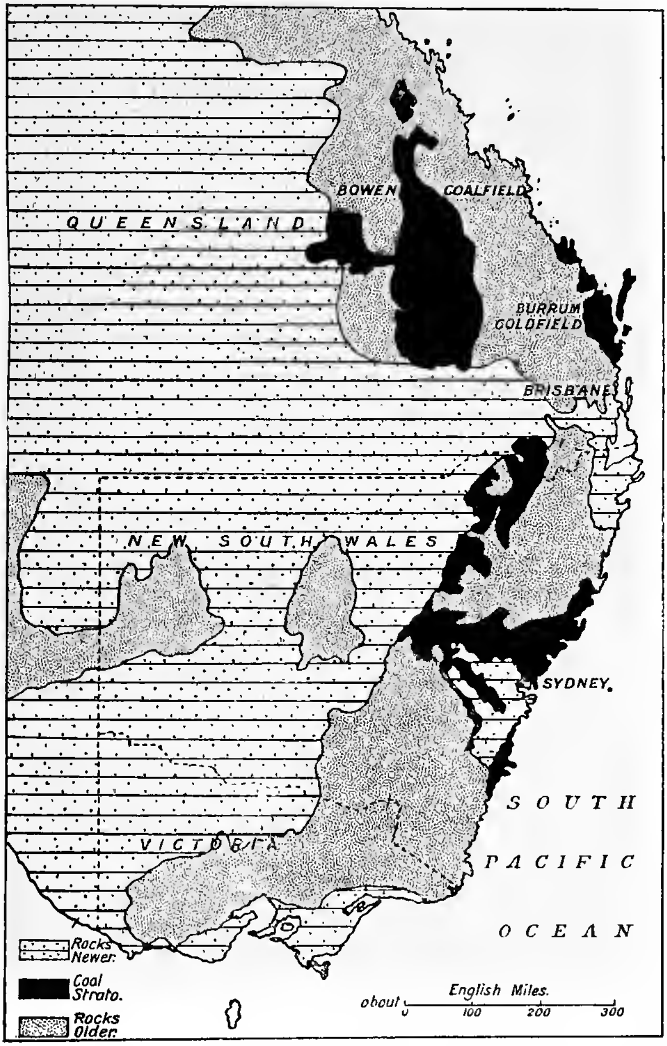


Fig. 4.—The Permo-Carboniferous Coalfields of Eastern Australia.

and semi-anthracitic, 860; bituminous and some anthracitic, 43,070; coal and lignitic coal, 21,000; lignite, 78,160.

Central Europe with Russia in Europe contains considerable quantities of Carboniferous coal and great reserves of Brown coal of Jurassic and Tertiary (Eocene and Miocene) ages. Germany produces an annual output of over 50 million tons of Brown coal, ranging from true Brown coal (Glanzkohle), with an analysis of: Carbon, 82·00; hydrogen, 4·20; oxygen and nitrogen, 5·9; ash, 7·9 per cent.; to earthy coal containing—Carbon, 57·43; hydrogen, 5·58; oxygen and nitrogen, 24·83; ash, 11·86. All countries bordering on the Mediterranean are poor in coal.

China is reported to possess fabulous amounts of Upper Carboniferous coal in the Po-shan formation of Shan-tung and the Shan-si formation of Chi-li and central Shan-si. Japan does not possess any coals of Palæozoic age, but the Tertiary coals of Kyūshū and Hokkaido are of good quality.

Since 1893 India (Fig. 3) has become one of the important coal-producing regions in the East. The many isolated coal-basins are estimated to contain a reserve of over 9,000 million of tons in an area of 35,000 square miles. The chief coalfields belong to the lower division of the peninsula development of the Gondwana System, which corresponds to the Upper Carboniferous, Permian, and Triassic formations of Europe.

Australia and South Africa are the chief coal regions in the Southern Hemisphere, those of Australia ranking first. The chief Australian coalfields are situated in New South Wales, with a reserve of over 10,000 millions of tons, and in Queensland. They belong to late Palæozoic and early Mesozoic formations. In South Africa the chief coals are found in the Karroo formation, which is extensively developed and covers great areas in Cape Colony, Natal, and the Transvaal. It is generally agreed that the important coals belong to the lower beds of the Karroo formation, though this part is unproductive in Cape Colony, where the coal-seams lie in the Upper Karroo beds. Most African coals give a high percentage of ash, those of the Upper Karroo yielding between 20 and 30 per cent. of ash.

Photo] [*A. C. Seward.*

SIGILLARIA BRARDI, BRONGT. *Reduced.*

Photo] [*A. C. Seward*

GLOSSOPTERIS BROWNIANA, BRONGT. *Reduced.*

CHAPTER V

FOSSILS AS ZONAL INDICES

THE various sedimentary strata comprising the greater portion of the rock sequence, from the oldest up to the most recently deposited, do not materially differ either in appearance or lithological characters from one another, Thus a limestone, sandstone, or shale of Cambrian, Ordovician, or Silurian age may bear a close resemblance to one of Carboniferous or later age. In the Warwickshire Coalfield, black shales, now proved to belong to the Cambrian formation, are underlain by a hard quartzitic sandstone, and so close is the general resemblance of these shales and quartzites to the overlying quartzitic sandstones and shales of Coal-measure age that geologists once included them in the Carboniferous system. Again, in Pembrokeshire and North Wales, the black shales of Ordovician and Silurian ages are in appearance indistinguishable from the neighbouring Carboniferous shales, and even in recent years shafts have been sunk in these fossiliferous black shales with the expectation of finding workable coals. In the attempts now being made to prove coal in the south-eastern counties of England, and to a greater extent in Northern France, black shales are often encountered in borings, the age of which cannot be judged by their lithological characters, but can only be determined by the fossils.

Red strata very often both underlie and overlie the Carboniferous rocks of Europe—the one of Devonian, the other of Triassic age. Lithologically, it is often impossible to distinguish one from the other; yet the importance of being able to do so is evident, for if the red strata are of Triassic age, then the coal-bearing Carboniferous rocks may occur below them; while if they are of Devonian age, the quest for coal beneath them is useless, since, as before stated, coal makes its first appearance in the Carboniferous formation.

The geologist has, fortunately, an infallible means of

distinguishing the older from the newer set of strata, even though similar both in colour and mineral composition. The means of determination lies in the distinct characteristics of the fossils met with in the different geological formations. Among the pre-Carboniferous rocks *Graptolites* (*sensu stricto*) do not occur above the Silurian. Therefore the presence of even a fragment of a *Graptolite* indicates at once a horizon far older than any coal-bearing formations in the world. Again, the *Trilobites* met with in the older rocks are of a species quite distinct from those occurring in rocks of Carboniferous age. The pre-Carboniferous strata also contain numerous other invertebrate fossils, of which, though the genera may be similar, the species are readily distinguishable from any met with in rocks of later ages. The fish remains, too, in the formations older than the Carboniferous, belong, as a whole, to different types from those met with in the Carboniferous and later periods.

The occurrence of fossils, then, or even one fossil, such as a *Graptolite*, will at once determine whether the strata in which they occur are of Carboniferous or older age, even though lithologically the strata may be indistinguishable. The fauna and flora of the Secondary and Tertiary formations, as is well known, differ essentially from those found in the Palæozoic rocks.

We have next to consider the characteristic fossils of the Carboniferous system, and how far they may serve to distinguish one part of the system from another.

The Carboniferous period was essentially the age of cryptogamic plants—that is, plants of simple organization, such as horsetails, ferns, mosses, etc. The vegetation did not reach a higher stage than that of rudimentary palms. The palæobotany of the Carboniferous rocks, however, is undergoing revision, and plants formerly grouped with the Filices are now proved to belong to higher orders. Not only was there no marked predominance of ferns, but the majority of the fern-like plants were seed plants—Pteridosperms. All, or almost all, of the fronds of *Neuropteris* and *Alethopteris* belong to the spermophytes. Most of the fronds of *Sphenopteris* belong to the pteridophytes; while some fronds of *Pecopteris* are referable to the pteridophytes, and others to the spermophytes. On the whole, the Middle Coal-measure flora is less rich in true ferns than the Upper Coal-measures, as understood by palæobotanists. Much is also still being learned about the habitat of the Coal-measure

Photo] [*R. Kidston.*

PECOPTERIS ARBORESCENS, SCHL. SP. *Reduced.*

plants, especially about the species that lived submerged and partially submerged.

While the flora of the period belonged to a humble stage in plant evolution, the fauna shows a great advancement on the preceding forms. Bony fishes reach a high state of development, and air-breathing vertebrates make their first appearance. The presence of these in association with abundance of cryptogamic plants and the absence of the higher orders of Phanerogamous plants, therefore, serves to distinguish the Carboniferous from any preceding and succeeding formation.

We have now to see how far fossil evidence is of use in distinguishing one part of the Carboniferous formation from the other. Since this formation may, and often does, exceed 10,000 feet in thickness, and in England the coal-seams are practically restricted to one portion, it is evidently of importance to be able to recognize the coal-bearing from the non-coal-bearing Carboniferous strata.

The Carboniferous system of Western Europe and of the United States can be separated into a lower and an upper division. The lower division rarely contains workable seams, and the thickest and most valuable coals are met with in the upper division.

Fossils of the Lower Carboniferous Rocks.—In Europe the lower division (Dinantian) consists usually of highly fossiliferous limestones, fine-grained sandstones, and shales, the latter often bearing a close lithological resemblance to the sandstones and shales of the upper division.

Marine conditions generally prevailed in Europe throughout the Lower Carboniferous, and fresh-water phases, such as in the Calciferous Sandstone Series of Scotland, may be regarded as exceptional.

A very different fauna inhabited the Dinantian seas from those of the Upper Carboniferous period. Corals (*Syringopora reticulata, Zaphrentis, Lithostrotion basaltiforme,* and *Dibunophyllum*) were abundant, and are not found irregularly distributed, but arranged in sequence, *Dibunophyllum,* for instance, indicating a higher horizon than that in which most of the species of *Zaphrentis* occur. Some of the Brachiopods, Lamellibranchs, and Cephalopods are common to the Dinantian and Upper Carboniferous strata; but others, such as *Productus gigantea,* and *Prolecanites compressus,* are not found above the lower division.

In cases where the Lower Carboniferous strata consist

of black shales and mudstones most of the fossils met with in the limestone do not occur, but are replaced by animal forms suited to the changed conditions from clear and open seas to muddy water. The shells of these animals, however, are very distinct from those which lived on the muddy flats and in the estuaries and shallow Upper Carboniferous seas (*cf.* Figs. 5 and 6, pp. 47 and 49).

There is, however, one notable exception. Bands containing a specialized marine fauna, containing, among other shells, *Prothyris elegans, Sanguinolites occidentalis,* and *Schizodus wheeleri,* are found on two or more horizons in the Lower Carboniferous formation of Scotland. This fauna is reminiscent of a Coal-measure fauna of the United States, and, moreover, *Prothyris elegans* occurs high up in the Middle Coal-measures at Maltby Colliery in Yorkshire, while *Sanguinolites occidentalis* and *Schizodus wheeleri* have been recorded from the top part of the Millstone Grits near Hirwain in the South Wales Coalfield.

Plant remains are somewhat rare in the Lower Carboniferous rocks. Many of the genera and most of the species are distinct from those found in the Upper Carboniferous strata. Thus *Lepidodendron veltheimianum* (Plate VIII.) is a species confined to the lower division.

Fossils of the Upper Carboniferous Rocks.—The upper division of the Carboniferous system contains, as we have said, the chief coal-seams in Europe and North America. The fauna indicates that the strata were laid down partly under fresh-water and partly under estuarine and marine conditions. Taken collectively, the strata consist of alternating sandstones and shales, with an occasional thin band of earthy limestone.

The seams of coal are very unevenly distributed, often occurring in groups, and zones rich in coals are often separated from one another by barren strata. Many of the better-class seams are found to occupy definite positions in the Coal-measure sequence. It is obviously of great use, therefore, to be able to distinguish the horizons of the productive from the unproductive strata, and to recognize the positions of the more important coal-seams.

Palæontologists admit that the fossils of the Upper Carboniferous strata, whether plant or animal, do not strictly lend themselves to what is known as the zonal method. There are hardly any proved restrictions of genera or species to zones of limited thickness over wide

Plate III.

Photo] [*R. Kidston.*

SIGILLARIA RUGOSA, BRONGT. *Natural Size.*

areas, as is the case with the *Graptolites* of Ordovician and Silurian ages; nor can it be said that any such zones and subzones have been established as those afforded by the *Ammonites* of the Jurassic period and the *Echinodermata* of the Cretaceous period.

Viewed broadly, the fossils of the Upper Carboniferous strata have a wide vertical range. A plant or shell makes its appearance, attains a maximum development, and then dies out. As one genus or species becomes rare another form makes its first appearance in limited numbers, then becomes predominant, and finally passes away. But meanwhile the sediments have accumulated to a great thickness.

The distribution of the plants is considered to be governed by the law of evolution, but that of the mud-loving mollusca seems to be dependent on local conditions of sedimentation; for the majority of the species occur at different horizons in different places according to environment, and changes due to evolution cannot be demonstrated.

Over limited areas a species or genus is not infrequently restricted to a particular horizon, but may mark quite a different horizon in another region. It is therefore necessary to distinguish between those fossils, which everywhere indicate a high or low position in a sequence from those forms which, locally restricted to a particular bed or group, only possess a local value, since in other areas they are found at other horizons.

The Upper Carboniferous strata of Great Britain are divided into two series—a Lower or Millstone Grit series and an Upper or Coal-measure series. For the latter several classifications have been suggested, the terms Upper, Middle, and Lower Coal-measures being the best known. So far as these terms are merely taken to imply a relative position in any given sequence they serve a useful purpose, though they are valueless in comparing one coalfield with another.

Plant remains are rare in the Millstone Grit series, and afford little help in the identification of horizons. The fauna is almost exclusively marine, and in this respect differs from the overlying Coal-measures. The series is recognized in part by the absence of the plants and of the estuarine and fresh-water shells common to the subdivisions of the Upper, Middle, and Lower Coal-measures.

The distribution of the various plants and mollusca

throughout the Coal-measures serves to identify the position of certain groups of strata. The zones formed by the vertical distribution of plants are of great thickness. Instances are rare where a plant, or an assemblage of plants, defines one stratum, and where this does happen it is only of local significance. On the other hand, plants form a reliable index in determining whether a group of Coal-measure strata occupies a high or low position in the general sequence.

The Upper Coal-measure age of a series of strata is assured by the presence of *Pecopteris arborescens* (Plate II., p. 40), *Pecopteris unita,* and *Alethopteris serli,* which are unknown in the Lower and rare in the Middle Coal-measures. The occurrence of *Sigillaria rugosa* (Plate III., p. 42), *Sphenopteris obtusiloba* (Plate VII., p. 50), and *Neuropteris gigantea* (Plate IV., p. 44) will determine the age to be Lower or Middle Coal-measures, since these forms are restricted to these subdivisions. *Alethopteris lonchitica* (Plate V., p. 47) is a common form in the Middle Coal-measures, but occurs much less profusely in the Lower Coal-measures, and is rarely found in the Upper Coal-measures. *Stigmaria ficoides* (Plate VI., p. 49) is a plant common to all the subdivisions of the Upper Carboniferous series, and is therefore valueless as an index of horizon. Palæobotanists place reliance on the presence of many other plants of rarer occurrence—the abundance of some forms, and the exclusion of others—or on a special assemblage of certain plants. Such intimate knowledge, however, belongs to the specialist, and is seldom attainable by the field geologist.

Plants, then, as an index of horizon, are of service only in a broad, general sense. It is otherwise with the mollusca. These not only indicate a relatively high or low position in a local sequence, but in many coalfields fix the horizon of a particular bed, and thus identify the position of a seam of coal from place to place.

The mollusca can be referred to two faunas, which keep apart from each other, and are never found associated together in the same zone, though the two zones may be separated by only an inch, or even less, of shale or other material. One of the faunas is certainly marine, and since the two faunas never commingle, it is thought that the other represents the mollusca of an estuarine or fresh-water habitat.

The estuarine and fresh-water faunas occur throughout the Coal-measures, and are evenly distributed, but are

Plate IV.

Photo] [*R. Kidston.*

NEUROPTERIS GIGANTEA, STERNB. *Natural Size.*

sometimes aggregated in a bed a few feet in thickness. The marine shells, on the contrary, are met with only in definite bands, seldom exceeding 10 feet in thickness, and are restricted to the Middle and Lower divisions.

The fresh-water and estuarine mollusca belong to the order Lamellibranchiata, the chief forms being *Carbonicola* (*Anthracosia*), *Anthracomya*, and *Naiadites*. These have a wide distribution, and are the commonest shells met with in the Coal-measures throughout the world. Fluviatile and lacustrine Gasteropoda are much rarer, and are confined to a few coalfields, and not generally distributed like the Lamellibranchiata.

In the coalfields of Central England the various species of *Carbonicola*, *Anthracomya*, and *Naiadites* occur in a definite sequence. Most of the species have a wide vertical range, but a few are considered to be confined to particular bands. To what extent the vertical range of these species in the coalfields of Central England coincides with that in other British and foreign coalfields has not been ascertained as yet, but the available evidence seems to show that the succession of the fresh-water and estuarine Lamellibranchiata of Central England does not apply, except in a general way, to foreign coalfields.

It has been stated before that the occurrence of a certain species at any one place was largely governed by local conditions, and that the different species of Lamellibranchiata do not demonstrate any marked evolutionary change. The mollusca followed the sediments brought down, and the food these contained. Under varying conditions the animals would consequently migrate backwards and forwards from one district to another, and accommodate themselves to the food-supply. This does not necessarily invalidate their use in the determination of a local sequence, or even over a broad area like the coal-basin of Central England, which, though subject to fluctuations, certainly existed as an area of continuous deposition under like conditions throughout the Coal-measure period.

The succession of the Lamellibranchiate fauna established for the Midland coal-basin may not, therefore, hold good for other districts. It is, indeed, more likely that each separated area will present its own individual order of life forms, as deposition and consequent food-supply may have been arrested at one stage in one area and at another stage in a separate area.

In the Midland coal-basin of Central England the species of *Carbonicola*, *Anthracomya*, and *Naiadites* appear in the following order from the base of the Coal-measures upwards:

Carbonicola robusta (Fig. 5).—This fossil is found in great numbers in the strata containing the chief seams of coal, and occurs in many of the so-called mussel bands. Isolated specimens are met with low down in the Coal-measure sequence, but the species dies out in the Middle Coal-measures. It may be safely regarded as indicative of the lower seams of the Middle Coal-measures.

Carbonicola turgida (Fig. 5).—Like the last-mentioned fossil, this species is associated with the chief seams of coal, and does not ascend into the Upper Coal-measures. It is found singly or in association with *Carbonicola subrotunda* and *Carbonicola gibbosa*.

Carbonicola subconstricta (Fig. 5).—This form is also confined to the Middle or productive series.

Carbonicola acuta and *Carbonicola aquilina* (Fig. 5).—Both these species have a wide range throughout the Lower and Middle Coal-measures. Though they are among the commonest fossils found in the Coal-measures, they cannot be assigned to any distinct zones. *Carbonicola acuta* is common in the so-called mussel-beds, where it occurs in association with the species above mentioned. None of these species of *Carbonicola* occurs in the Upper Coal-measures.

Naiadites quadrata (Fig. 5).—This is also a common fossil in the Middle Coal-measures, either occurring alone or in association with *Naiadites carinata* and *Naiadites modiolaris* (Fig. 5). It is unknown in the Upper and very rare or absent in the Lower Coal-measures.

Anthracomya williamsoni (Fig. 5) and *Anthracomya modiolaris*.—Both these species are confined to the Middle Coal-measures, and are of much less common occurrence than the species of *Carbonicola* and *Naiadites*.

Anthracomya adamsi (Fig. 5).—This has a very restricted range in the Middle Coal-measures.

All these fossils are confined to the Coal-measure strata situated between the top of the Millstone Grit and the base of the Upper Coal-measures, and may certainly be regarded as representing the estuarine development of the Lamellibranchiata at this period.

We shall now consider the fossils of the Upper Coal-measures, taking this term to include the barren strata

Plate V.

Photo] [*R. Kidston.*

ALETHOPTERIS LONCHITICA, SCHL. SP. *Natural Size.*

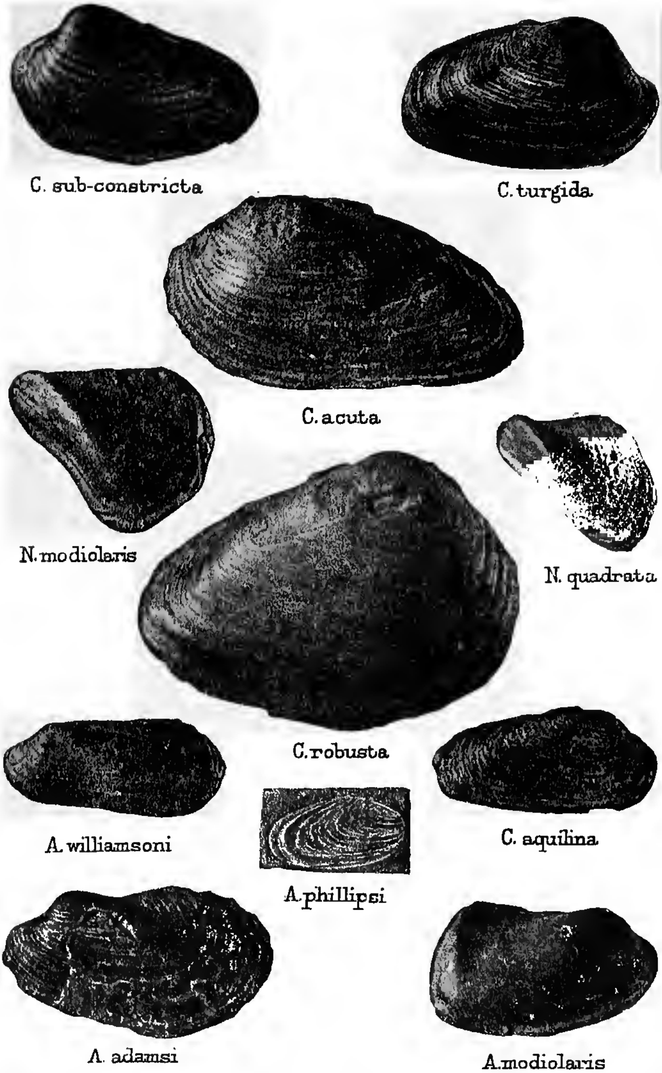


FIG. 5.—CARBONICOLA (C.); ANTHRACOMYA (A.); NAIADITES (N.) FROM THE ENGLISH COAL-MEASURES.

overlying the Middle Coal-measures of the Midland Province and the measures above the Pennant rock in the Southern Province (p. 111).

The commonest fossil met with is *Anthracomya phillipsi* (Fig. 5), and throughout the Midland coal-basin it indicates a high position in the Coal-measures, for it first appears towards the top of the Middle Coal-measures, and becomes abundant only in the lower part of the Upper Coal-measures. In Scotland, however, this shell, or one resembling it, occurs in the beds of the Calciferous Sandstone Series.

The last survivor of the fresh-water Lamellibranchiata is *Anthracomya calcifera*, a small shell met with high up in the Upper Coal-measures, but having a limited vertical distribution.

We have now traced the vertical distribution of the Coal-measure Lamellibranchiata in the order in which they occur in the Midland coal-basin. To what extent this order holds good for other British coalfields has not been determined.

In the North of England and in South Wales *Carbonicola robusta* appears to be restricted to low horizons, while *Anthracomya phillipsi* indicates a high position. It does not, however, appear safe at present to rely upon these or other species as a definite means of correlation, though locally a species, or several species, may always be found in a particular bed for a considerable distance, and so serve as a useful mark of identification of much local value.

The marine mollusca are more varied both in genera and species than the estuarine and fresh-water forms. Not only the Lamellibranchiata, but also the orders of the Gasteropoda and Cephalopoda, are represented by many genera and species. Few of the forms, however, are peculiar to the Coal-measures, and the majority are identical with, or have a close affinity to, the marine mollusca of the Lower Carboniferous and the Millstone Grits.

The chief invertebrate fossils common to both divisions are:

Brachiopoda.
- Lingula mytiliodes (Sow.).
- Orbiculoidea (Discina) nitida (Phill.).
- Productus (scabriculocostate form).
- Productus scabriculus (Mart.).
- Spirifer bisulcatus (Sow.).

Lamellibranchiata.
- Ctenodonta lævirostris (Porth.).
- Leiopteria longirostris (Hind).
- Nucula gibbosa (Flem.).
- Nucula æqualis (Sow.).
- Nuculana sharmani (R. Eth. fil.).

Plate VI.

Photo] [*R. Kidston.*

STIGMARIA FICOIDES, STERNB. SP. *Reduced.*

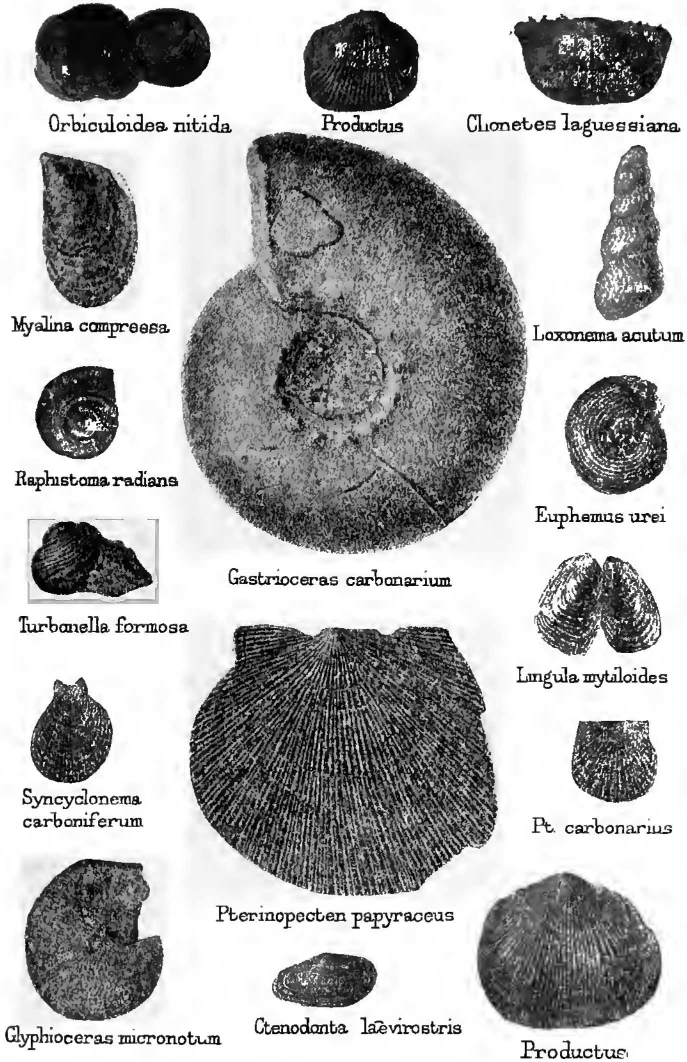


FIG. 6.—MARINE SHELLS FROM THE COAL-MEASURES OF CENTRAL ENGLAND.

Lamellibranchiata—*continued.*

Posidoniella lævis (Brown).
Posidoniella minor (Brown).
Pseudamusium fibrillosum (Salter).
Pterinopecten carbonarius (Hind).
Pterinopecten papyraceus (Sow.).
Syncyclonema carboniferum (Hind).

Gasteropoda.

Euphemus urei.
Raphistoma radians (de Kon.).

Cephalopoda.

Cœlonautilus, *cf.* subsulcatus (Phill.).
Conularia quadrisulcata (Sow.).
Dimorphoceras gilbertsoni (Phill.).
Dimorphoceras loonyi (Phill.).
Gastrioceras coronatum (Foord and Crick).
Glyphioceras phillipsi (Foord and Crick).
Glyphioceras reticulatum (Phill.).
Nomismoceras ornatum (Foord and Crick).
Pleuronautilus armatus (Sow.).
Pleuronautilus falcatus (Sow.).
Pleuronautilus rotifer (Salter).

The occurrence of these fossils alone would therefore only show that the sandstones and shales in which they occur are of Carboniferous age. The presence of the following assemblage would, however, indicate an Upper Carboniferous age of an English sequence, since, so far as is known, they are only met with in this division of the Carboniferous strata in England. Some of the marine shells, now only known in the Lower Carboniferous, may ultimately be found in the marine bands of the Upper Carboniferous rocks; others, again, given in the following list, and at present only known to occur in later Carboniferous times, may have made their appearance during the deposition of the Lower Carboniferous strata.

Brachiopoda.

Ambocœlia carbonaria (Hind).
Chonetes aff. laguessiana (de Kon.).
Productus anthrax (Hind).

Lamellibranchiata.

Ctenodonta undulata (Phill.).
Nucula oblonga (M'Coy.).
Nuculana acuta (Sow.).
Posidoniella sulcata (Hind).

Gasteropoda.

Loxonema acutum (de Kon.).
Naticopsis brevispira (de Ryck.).

Gasteropoda—*continued.*

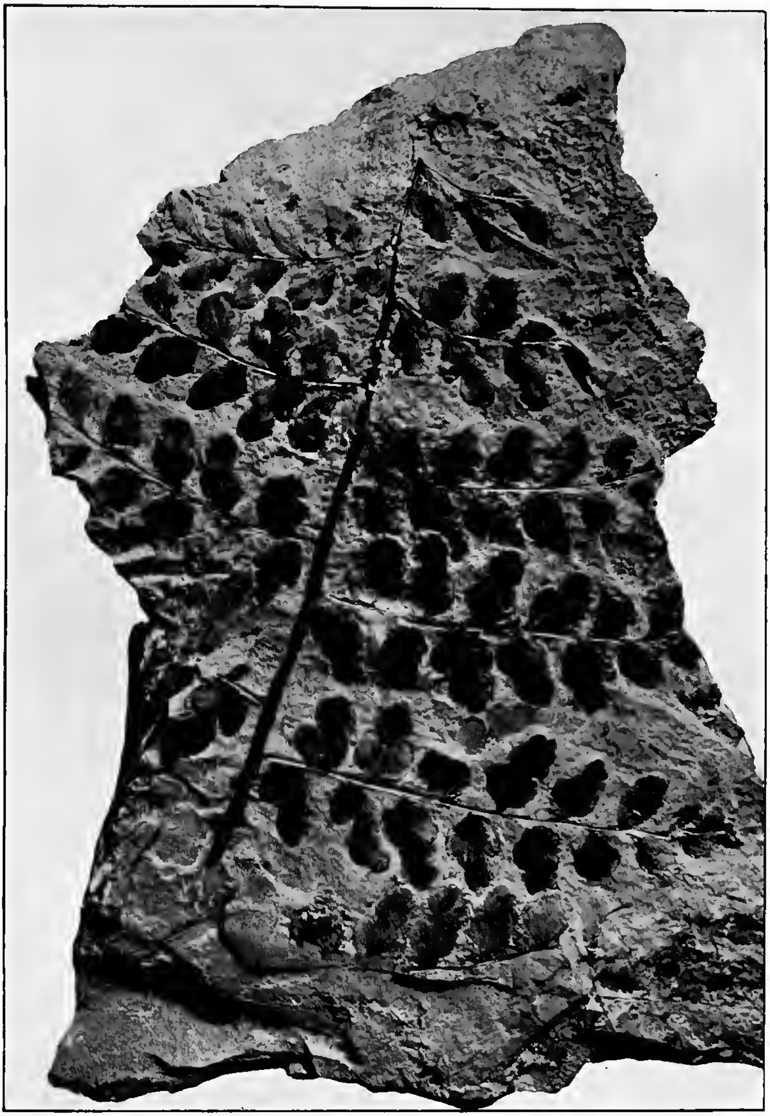
Turbonellina formosa (de Kon.).

Cephalopoda.

Ephippioceras costatum (Foord).
Gastrioceras carbonarium (L. von Buch.).
Gastrioceras listeri (Martin).
Glyphioceras paucilobum (Phill.).
Pleuronautilus costatus (Hind).
Temnocheilus carbonarius (Foord).
Temnocheilus concavus (Sow.).

The material in which the fossils are contained is invariably a shale, either dark blue in colour and of greasy appear-

Plate VII.



Photo] [*R. Kidston.*

SPHENOPTERIS OBTUSILOBA, BRONGT. *Natural Size.*

ance, or jet black, but non-carbonaceous. Sandy, light grey shales or black, highly carbonaceous shales seldom, if ever, contain marine organisms. The fossils are more frequently preserved in iron pyrites than is the case with the fresh-water and estuarine Lamellibranchiata. Argillaceo-calcareous ironstones in nodules or in thin bands are common, and usually contain the best-preserved specimens. The greasy blue shales ('soapy binds' of the English miner) contain the richest and most varied fauna, while that of the darker-coloured shales is usually restricted to species of *Goniatites*, *Pterinopecten papyraceus*, *Lingula*, and *Discina*.

The marine bands vary from a few inches to over 30 feet in thickness, the thickest beds being those formed of the greasy blue shales with ironstone nodules.

Excluding such bands as have so far been recognized only over very limited areas and the beds yielding *Lingula* and *Discina* only, the marine horizons in the Coal-measures do not exceed four or five in number in Central England, where they have been most systematically investigated. Of these, two only have proved to be of wide distribution.

The lowest band, containing chiefly *Goniatites* and *Pterinopecten papyraceus*, is only a few feet in thickness, and forms the roof of the lowest seam of coal in the Lower Coal-measures throughout the Midland Province.

The other marine horizon, lying high up in the Middle Coal-measures, contains the fauna given in the list (pp. 48 and 50). This band has been met with in North Staffordshire, and traced over a wide area on the east of the Pennine Chain, from the vicinity of Nottingham to the neighbourhood of Doncaster and Pontefract. It always occupies the same relative position to the Top Hard Coal of Nottinghamshire and its equivalent, the Barnsley Coal of the Yorkshire Coalfield.

Between these two generally recognized bands, and again higher up in the sequence, other marine beds are recorded from several coalfields, but it remains to be proved whether these occupy definite positions or if they merely represent local marine incursions in a sequence mainly estuarine or fresh-water, as determined by the character of its fossil contents, such as *Carbonicola*, *Anthracomya*, and *Naiadites*.

Thin bands of shale, containing *Lingula* and *Discina*, or only the former, are of more common occurrence in the Midland Coal-measures than is usually accepted. The beds are seldom more than a few inches thick, and though perhaps

only of local occurrence, unless their existence has escaped notice owing to the thinness of the bands and the smallness of the fossils, they are easily recognized by the glistening, scale-like character of the horny shells. Some fish scales and the smaller forms of *Anthracomya* might be mistaken for a *Lingula*, but the usually ornamented character of the fish scales and the calcareous shell of *Anthracomya* will distinguish these fossils from the plain chitinous shell of the small Brachiopod.

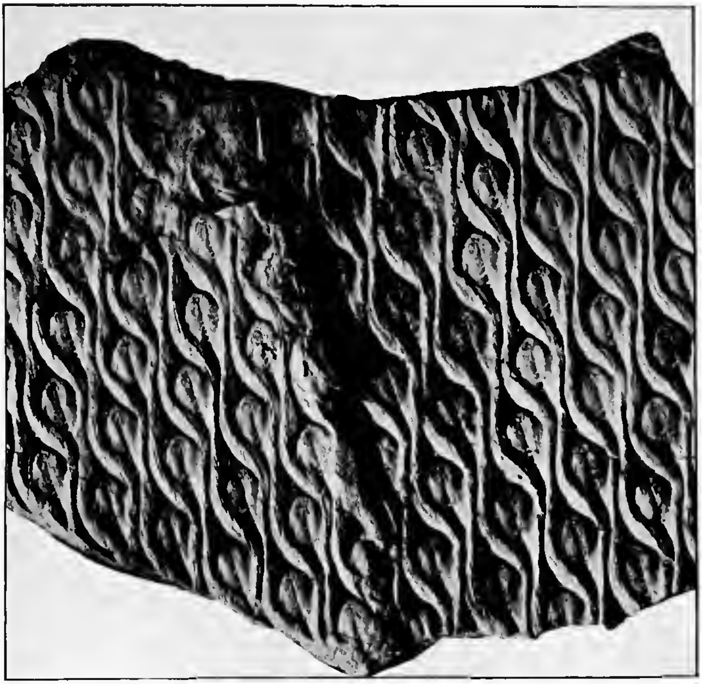
In tracing a band containing *Lingula*, it is frequently found to pass laterally into a bed containing *Goniatites* and *Pterinopecten*. The Brachiopod then becomes rare or absent, as if the presence of this animal marked a change from a purely marine phase to one less favourable to the existence of the marine organisms.

In Great Britain the highest Coal-measures do not contain workable seams. In the United States the Dunkard formation, placed by some geologists in the Carboniferous and by others in the Permian, is likewise practically barren of coals. In Central France and Germany, however, a group of strata (Stephanian) of lacustrine origin contains many valuable seams. The flora is distinctive of the highest Coal-measures in Europe, but is associated with many other plants not found in Britain.

Fossils of the Later Formations.—In the Southern Hemisphere—Australia, India, South Africa, and South America—the chief coal-bearing formations are of Permo-Carboniferous, Permian, and Triassic ages. The flora of the Permo-Carboniferous is peculiar, and is easily recognizable from that of the later formations by the presence of the fossil plants *Glossopteris browniana* (Plate VIII., p. 52) and *Sigillaria brardi* (Plate I., p. 38).

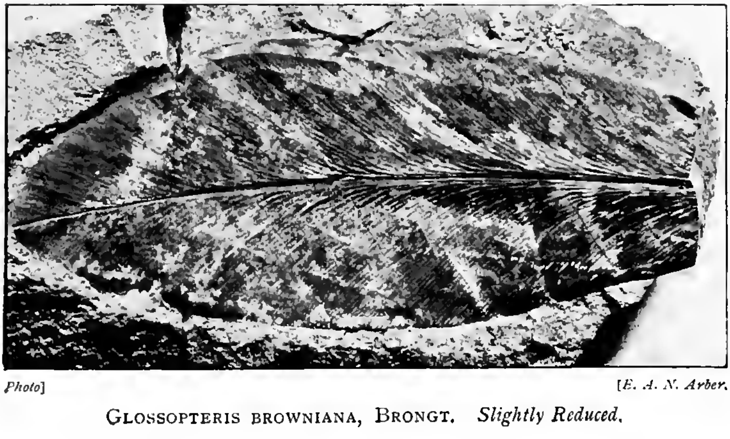
Positions among the Permo-Carboniferous rocks is roughly determined by the vertical distribution of the Reptilia. The question of determining the age of the coal formations of the Mesozoic and Tertiary periods by means of the fossils does not at present particularly attract the attention of the prospector for coal, since in most European countries coal-mining enterprise is chiefly directed to the exploitation of the more important Carboniferous coals, while the Mesozoic and Tertiary coals, besides being of inferior value, lie at shallow depths, and are readily exploited.

In Alaska good coals of Carboniferous age exist side by side with important seams of Mesozoic or Tertiary ages;



Photo] [*R. Kidston.*

LEPIDODENDRON VELTHEIMIANUM, STERNB. *Natural Size.*



Photo] [*E. A. N. Arber.*

GLOSSOPTERIS BROWNIANA, BRONGT. *Slightly Reduced.*

but the great distinction between the lowly organized flora of the Carboniferous and the higher Cycadaceous and Dicotyledonous flora of the Mesozoic and Tertiary formations will readily determine the age of any coal-bearing strata in which these fossils are found.

The flora of the chief coal-bearing formation of the Southern Hemisphere is known as the Glossopteris flora (Plates I. and VIII.), and is characteristic.

Concluding Remarks.—The most valuable coals belong, as before stated, to the Carboniferous system, and in the past coal-mining has been chiefly carried on in those regions where the Coal-measures lie at the surface. Now, however, explorations are being extended into areas where the character or even the existence of coal-bearing rocks is often a matter of considerable speculation.

As we have shown, the fossils afford a reliable guide in determining positions in the sequence. Since, however, the Coal-measure strata are so similar in appearance, it is useful in the case of a boring or shaft passing through several hundred feet of such strata to know in what kind of rocks the fossils, distinctive of definite horizons, may occur.

Beds containing marine fossils should be looked for among the blue-grey shales, and in the calcareous clay-ironstones commonly associated with them, and not in the more arenaceous rocks or in black carbonaceous shales. Plants, on the other hand, should be searched for in these sandy shales, while the estuarine lamellibranchs may be expected in the jet-black shales and in the ironstones that almost invariably accompany them.

The use of fossils to fix horizons among the strata of the Coal-measures may be as much abused, and lead to as many mistakes as the old, and for a long time the only practice of taking a sandstone, clay band, seam of coal, or a series of sandstones and coals, as an indication of position, since lithological characters show many variations.

The determination of a horizon from the occurrence of a single fossil, whether plant or animal, is a fatal error, and has frequently led to very false interpretations. In the Upper Coal-measures, for instance, a profusion of *Alethopteris serli* in association with *Pecopteris arborescens* and *P unita*, and the absence of many common Middle Coal-measure plants, can be relied upon in assigning the strata in which they occur to the Upper Coal-measures. But the

plants of the Upper series make their appearance towards the summit of the Middle series, and further research may discover them in the Lower series.

As our knowledge of the vertical distribution of the fossil plants increases, a form, for a long time considered to belong to a low horizon, is found to occur, though not in profusion, at a higher horizon, just as a high zonal plant is found, though not abundantly, at a much lower level. Conclusions, therefore, based solely on the occurrence of a single fossil plant would in either of these cases be quite misleading; the field of observation must be sufficiently large, the fossil plants abundant, and the knowledge of a particular district sufficiently extensive. It is necessary to ascertain whether the absence of certain plants is due to the small amount of material examined, or whether the local conditions were not favourable to their preservation, before it is safe to conclude that certain forms did not exist side by side with those found in a fossil state.

The same precaution is necessary in using the mollusca, whether marine, estuarine, or fresh-water, as zonal indices. In the absence of low zonal forms of *Carbonicola* and *Anthracomya* the presence of *Anthracomya phillipsi* can be relied on as a safe index of a high position in the Coal-measure sequence in the Midland area, since in those coalfields in which extensive collecting has been done the general absence of this fossil has been proved in the measures in which forms like *Carbonicola turgida* and *C. robusta* are present. But it would not be safe to assume that this rule holds good in other countries, and, indeed, on the Continent, and, as mentioned above, in Scotland also, *Anthracomya phillipsi* occurs below the zone of *Carbonicola robusta* and *C. turgida*, but even here we are not aware that it is found in association with these fossils.

Fresh information on the distribution of fossils tends as a rule to lessen the number of forms originally considered as restricted to definite horizons, and to show that each district has its own peculiar floral and faunal distribution, dependent upon local conditions or the accident of preservation, though each geological province may possess distinctive palæontological characters useful as a whole in extended correlation, but of little service to the miner.

The determination of horizons in the Coal-measures by means of fossils, whether plant or animal, perhaps still must be regarded as on trial, since the amount of material

to be dealt with is so great, and active research in many districts is not common. In numerous sinkings and underground explorations, indeed, the material has not even been examined, or at any rate only partially searched, for fossils. This being the case, it is as unwise at present to place complete confidence in fossils as zonal indices in the Carboniferous sequence as it is to cast entire discredit on the whole method.

Fossiliferous bands are certainly of great importance when a valuable coal lies among a thick mass of strata in which there are often no well-developed coal-seams or rock bands. This is the case in the East Yorkshire Coalfield, where the Barnsley Coal lies at the base of about 1,100 feet of strata containing many seams, but none of them of sufficient importance or sufficiently distinctive in character to have received special notice in the records of old pit sinkings. Towards the middle of the strata above the Barnsley Coal a bed occurs containing fossils peculiar to this band, and not met with in any other beds above the Barnsley Coal, though they occur in beds below and even in the Millstone Grits. While, therefore, the strata above this coal possess no very distinctive lithological characters, this band can be recognized by the peculiar assemblage of fossils. It therefore serves as an index of position among a great thickness of strata of which one portion is very similar to another.

The Bullion Coal of Lancashire, the Crabtree Coal of North Staffordshire, and the Pecten Bed and Alton Coal of Yorkshire and Derbyshire, afford other examples of a coal lying amidst a considerable thickness of barren strata, but readily identifiable by the fossils met with in the roof shales.

These fossiliferous bands, used merely as indices of position, cannot be regarded as of more value than a known seam of coal possessing marked characters, a bed of sandstone, or a local development of one particular kind of rock; but they certainly do afford confirmatory evidence, and sometimes constitute the only reliable index, of position in a local sequence.

Considerable experience is needed to recognize the species and often the genus of a fossil, but a nuntrained eye will scarcely fail to discriminate between the fossils of a marine band (Fig. 6, p. 49) and those of an estuarine bed; nor can the fossil assemblage of a rich zone like that above the

Gin Mine Coal be mistaken for one above the Crabtree Coal of North Staffordshire or for the one above the Deep Hard Coal of Derbyshire (p. 179). These three separate horizons contain fossils in common, but in the higher (Gin Mine) several species and genera of peculiar and easily recognizable characters, and unknown in the lower Coal-measures, are always met with.

CHAPTER VI

PROSPECTING AND BORING

FOSSIL evidence will in most cases correctly determine whether a formation is or is not likely to contain coal. In Europe and North America strata containing Upper Carboniferous plants, in the majority of cases, are coal-bearing; while in the Southern Hemisphere strata yielding the fossil plants *Glossopteris* and *Sigillaria* generally contain coals. The probability of coal existing in formations newer than the Carboniferous or newer than those containing *Glossopteris* will depend upon the character of the sediments. Since coal has been formed out of vegetable material growing on the spot now occupied by a seam of coal or from vegetable débris floated out and deposited in water in near proximity to land, coals will not occur in sediments whose deep-sea origin is evident from the nature of the fossils. Thus, among the later Mesozoic and Tertiary formations coal does not usually occur in the essentially marine sediments of these formations, but in the strata of estuarine and fresh-water origin.

Coal rapidly perishes at the surface. It is, therefore, seldom seen in natural sections, except in sea-cliffs, as along the Durham, Fifeshire, and Pembrokeshire coasts. It was the occurrence of coal in the sea-cliffs in New South Wales, near Sydney, and in New Zealand, near Dunedin, that atrracted the attention of the early settlers. Even where deep valleys have intersected seams of coal the outcrops are seldom visible, as rain-wash and vegetation commonly conceal them. Coal-seams are sometimes visible in the rocky sides and beds of rapid streams and along the faces of recent landslips.

As before stated, a coal-seam is frequently overlain by a water-bearing sandstone, and underlain by an impervious layer of shale or clay. The outcrop or 'basset edge' of a coal-seam is in consequence often indicated by a line of wet ground, on which rushes and other marsh plants grow.

Coal-seams and the closely associated shales and clays usually contain iron pyrites, which is readily decomposed, and gives rise to protoxide of iron, which is soluble in water. The water containing these soluble iron salts, when exposed to the atmosphere, deposits the insoluble sesquioxide of iron. If, then, in an area known to be coal-bearing a line of chalybeate springs be followed along a valley-side, it not infrequently happens that a spot is reached affording a section of a seam. Changes in vegetation are also useful guides. Thus, in New South Wales *Eucalyptus albens*, a variety of white box, shows a great partiality for the Coal-measures, and identifies these at a distance from the darker-tinted varieties of these trees favouring the barren Hawkesbury Sandstone.

Sea-cliffs, the beds of streams having a rapid fall, cascades and waterfalls, the scarred faces of recent landslips, etc., afford as a rule the only, and certainly the best, natural sections of coal at the surface. Fragments of the harder varieties, such as anthracite and cannel, may occur in the alluvial deposits of streams and main waterways, and by following the stream towards its source the outcrop of the coal from which the fragments have come may be detected.

Such natural exposures of coal, however, are rare, and a stream or river-bed may not afford any reliable indication as to whether the rocks which crop out along its course are coal-bearing or otherwise. In South Africa prospecting along the spruits and valleys would not in many cases afford any indication that the strata composing the district were coal-bearing, owing to the wasting away of the coal for considerable distances along the outcrop.

In the Northern Hemisphere, within the zone of glaciation belonging to the Quaternary period, the surface clays and sands not infrequently contain fragments of coal or coal-shale. Such fragments may not indicate the near proximity of coal-bearing strata, but if the direction from which the ice travelled be known, the trail formed of the glacial detritus may be followed to its source. The gravels, sands, and boulder clays of the Vale of York, along the path of the Stainmoor Glacier, and those of the Midland Triassic plain, on which the Welsh glacier debouched, contain numerous coal fragments derived from seams cropping out in those regions over which these glaciers passed; but the rocks at the surface on which the glacial deposits rest are many miles distant from the outcrop of the coal strata. Some-

times a considerable mass of coal and coal-bearing strata has been carried far from its outcrop by glaciers, and this occurrence has been erroneously taken as evidence for the existence of a coalfield.

The presence of coal-bearing strata being suspected, the means employed to prove the number and thickness of the seams of coal will naturally vary according to circumstances. Where the strata lie almost horizontal and the country is but little dissected by valleys, a trial shaft or boring will give the most satisfactory results. Where, as in South Africa, the coal perishes along the valleys and in the hollows or pans, the trial shaft or boring—preferably a shaft where the thickness of strata to be penetrated is not great, and the general character of the rocks is known—should be placed on the higher ground, and not in a depression. Where intrusive igneous material is developed on a large scale, and is known to have a deleterious effect on the quality of the coals, a site for the experimental trial is chosen removed as far as possible from the neighbourhood of the igneous rock. If the strata thought to be coal-bearing are very steeply inclined, then a trench cut at right angles to the strike of the beds will afford a good chance of proving any seams of coal.

In areas close to existing workings, or where the certainty of finding coal at workable depths admits of little doubt, it is usual to commence sinking a shaft of the required diameter without any preliminary trials. In more remote districts, however, where the depth to the coal, its quality, and even its existence, are more or less speculative, attempts are generally made to prove the value of the unknown ground by sinking a trial-shaft or boring.

A trial-shaft undoubtedly gives the more satisfactory results, but owing to the expense necessarily involved, this method is only adopted in areas where the probability of finding coal is practically assured, though the quality, thickness, and number of the seams are more or less unknown factors. Where the risk is greater, boring is usually resorted to.

Boring for coal is not so simple an operation as it appears, and requires much more care and supervision than is generally thought to be the case. The system of drilling adopted must be one capable of producing cores of reasonable diameter—not less than 4 inches—of the strata passed through, and, what is a more difficult task, the drill is

required to draw a core of coal from which the quality, thickness, and component parts can be satisfactorily determined. A considerable measure of success has been achieved in obtaining cores of rock between 4 and 6 inches in diameter at depths exceeding 3,000 feet, but, with the exception of the harder varieties of coal, a system of drilling capable of producing good cores has as yet to be invented, though better results may be expected when the difficulties of the operation are more clearly understood.

Many borings have been successful in proving the position of numerous seams and their thicknesses to within a few inches, but have failed to produce a core of coal, and have practically resulted in commercial failure. A case is also known where a seam, subsequently proved to be 4 feet in thickness, passed notice altogether in the drillman's record, but was met with in the shaft which followed the experimental boring. Obviously the detection of the occurrence of a coal and the determination of its thickness depend to a great extent on the acuteness of the man in charge at the time the drill is passing through a coal which is not of sufficient hardness to yield a sound core, but of which the presence is only indicated by the quicker rate of drilling.

As regards the depth attainable by the diamond drill, the maximum of 6,572 feet bored in Upper Silesia far exceeds the limits at which coal-mining is at present considered practicable on the Continent, where the limit is generally placed at 4,900 feet depth. In Fifeshire a boring reached 4,000 feet, the limit as regards depth considered practicable for working coal in this country.

Although drills can far exceed the depth at present fixed upon as the limit of profitable coal-working, the production of a complete core of coal which would justify the necessary expenditure in sinking shafts to any great depths has not as yet been successfully accomplished, so that comparatively few borings have been followed by shaft-sinkings.

The object of any boring for coal is to obtain cores of the different strata passed through. The rotatory type of drill is, therefore, alone admissible. In this method the actual cutting is performed by a crown set with diamonds or by means of chisel edges placed at an angle round a crown, or, again, by the rasping action of chilled shot washed down to the bottom of the hole, where they find their way beneath the crown. Usually a combination of both methods is resorted to, chisel cutters being used for the softer rocks,

and diamonds or chilled shot for the harder varieties. The core is retained in a hollow inflexible cylinder, from 8 to 20 feet in length, known as the core-barrel.

In the Calyx drill the hydraulic cylinder forms an important feature. By means of a gauge connected by a high-pressure hose to the water in the cylinder the foreman in charge can usually obtain a good idea of the kind of rock being bored through. In boring through a hard rock, such as a sandstone, the pressure indicated by the gauge is much lower than in going through a soft substance like coal; it is obvious, however, that the gauge will not differentiate between a coal-seam and any other rock offering a similar resistance to the passage of the drill.

The existence of a hard or soft bed is thus indicated by the gauge, but without stopping the drill and drawing the core the composition of the particular strata being bored through can be ascertained only by the fragments or washings brought to the surface and issuing with the stream of water at the top of the hole. A great deal, therefore, depends on the care taken by the foreman.

In the case of a soft coal which is readily ground into powder by the action of the drill much of the fine material, it is thought, escapes capture, and, ascending through the bore-hole, reaches the surface in the stream of water continually flushing the hole. This escape water, with any sediment it may contain, flows through a series of troughs conveniently arranged at the surface, and supposed to catch the sediments brought up by the water. The coal-dust or pieces of coal eluding capture in the core-barrel and chip-cup should theoretically be retained here, and it is supposed that the fragments of coal which the core-barrel or chip-cup fails to retain are found in the slimes of the settling-troughs. Since, however, the stream of water entering the troughs ultimately escapes into a sluice or neighbouring stream, it seems quite possible for very finely divided coal to pass out of the troughs, and thus escape notice altogether. It is, however, denied that any loss of core occurs in this way.

The choice of a site for a boring depends largely on the royalty it is intended to prove, of which the extent is determined beforehand on both commercial and geological considerations. A good supply of water is also essential both for the engines and to keep the bore-hole continually flushed, and this must be taken into account in choosing

the site. The most suitable spot having been chosen, it is then necessary to decide upon the initial diameter of the hole. This depends, neglecting the cost, chiefly upon the nature of the strata to be penetrated.

The rocks forming the cover of most coal-bearing formations are generally favourable for drilling. Most of the coal-bearing strata, and especially the Coal-measure strata of Carboniferous age, consist of marls and clays, and strata of this nature swell up and have a tendency to close in on the hole. To obviate this it is necessary to case off these rocks by iron piping, and this repeated casing and lining of the hole naturally necessitates a diminution in its diameter. Under ordinary conditions, if it is desired to draw a core of coal, 4 to 7 inches in diameter at a depth exceeding 2,000 feet, the initial size of the hole should be not less than 18 inches across. Borings have been put down in which the diameter in the final stages was under 1 inch, and therefore practically useless. On nearing the horizon at which a seam of coal is expected it is preferable, whenever possible, to discontinue drilling at night, though in the case of deep holes this adds to the cost, and may sometimes be impracticable.

It is assumed that a hole starting straight proceeds vertically downwards to the bottom; few borings, however, achieve this desideratum, unexpected turnings from the perpendicular being of frequent occurrence. Absolute proofs of the amount of deviation have not, in many cases, been ascertained, and in some borings no allowance has been made for possible deviations from the vertical. In South Africa a deviation of 2,185 feet in a depth of 4,802 feet has been recorded, and in Germany as much as 47 degrees departure from the vertical at a depth of 750 feet has been notified.

Various methods for determining the amount and direction of the deviation have been tried, but most of them are open to criticism, though in many cases satisfactory results have been obtained. One of the commonest, but certainly one of the least reliable, is to lower down the hole a tube containing liquid gelatine or cement, and to note the angle at which it sets. In shallow holes this method may give a satisfactory result, but in deep holes the liquid may set, owing to the cooling effect of the water used to flush the hole, long before it reaches the place where the deviation is to be ascertained. The plan of using the effect of a

solution of hydrofluoric acid in etching a glass tube lowered down the hole is also resorted to, and may give a reliable result, since a solution of sufficient weakness can be used which does not act until the glass tube lowered down has reached the spot where the deviation is supposed to have taken place. Another plan is to employ electricity in fusing solid paraffin, or other liquefiable substances, after the tube has been placed in the required position in the hole.

The effect of a boring ceasing to be plumb is to give an exaggerated dip and thickness to the strata, the actual depth attained by the boring being unproved, unless the amount of deviation can be correctly ascertained. Whenever feasible, therefore, careful tests should always be made to find out whether the boring has turned from the vertical.

The preservation of the cores and the correct description of the strata passed through ranks of considerable importance. The notification of any fossils met with is also most desirable, as these may in many cases afford the only true index of position.

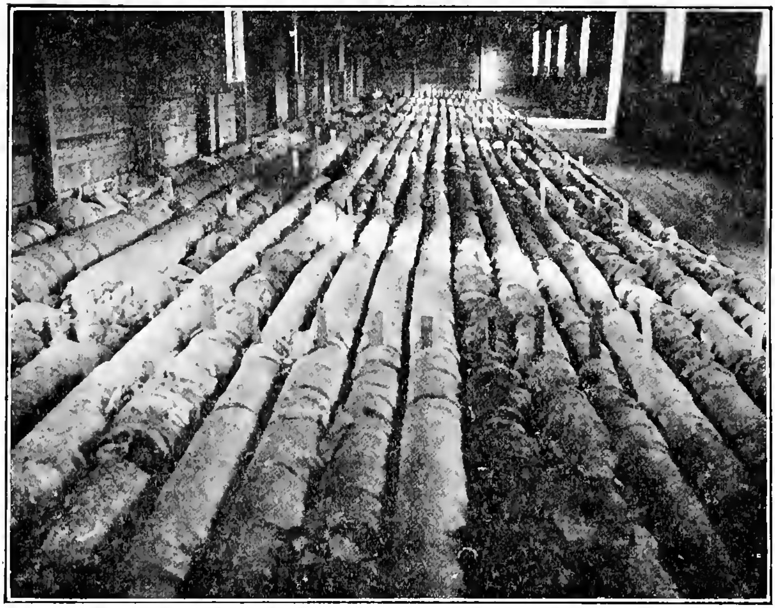
The most satisfactory method of keeping the cores so that they can be readily examined at intervals is to place them in a galvanized iron shed (Fig. 7). In the case of deep borings this shed should be from 50 to 100 feet in length, and of sufficient width to allow the cores to be arranged on the ground in a single tier, each length, say, of 100 feet being separated from the next by match-boarding. The frequent practice of arranging the cores in layers one above the other is to be deprecated.

The depths from which the cores are obtained should be inserted on them at frequent intervals by means of labels affixed by some adhesive not affected by damp.

A careful record of the boring as it proceeds is essential. This is usually left to the foreman, who states the depth bored, the amount of core drawn, and the amount lost. He is not as a rule, however, sufficiently acquainted with the rock sequence of the district to put into writing a correct description of the strata passed through. Instances occur where a bed, important from the evidence it affords of the position attained in a coal-bearing sequence, is described in terms quite misleading as to its character. It is advisable, therefore, to have the cores so arranged that they are readily accessible. The foreman's record can then

be checked from time to time so that any necessary alterations and additions can be made to the record.

On the completion of a boring a thorough survey of the bore-hole should be made, and lengths of core of important horizons—not merely chips, as is frequently the case—should be placed in boxes for future reference. If the entire cores are preserved so much the better; and where a boring is put down in an area where the rock sequence is



Photo] [J. Bircumshaw.

FIG. 7.—CORES AND CORE-SHED AT FARNSFIELD BORING, NOTTINGHAMSHIRE.

comparatively unknown, it is certainly advisable that the whole of the cores should be kept, since a horizon regarded as of little importance at the time may ultimately prove of value.

We have stated before that the production of a core of coal sufficient to identify the seam is seldom achieved, while to obtain rock-cores is a comparatively simple matter. Though borings may, therefore, prove unsuccessful in respect to the chief object—that of securing a core of coal—they seldom fail to produce good cores of rocks from which

important conclusions may be drawn as to the structure of the area, the depths of the seams, and the nature of the strata, whether water-bearing or not. In the case of mining royalties of considerable area boring may be discontinued at a stage when sufficient information has been attained as to the thickness and nature of the cover, whether water-bearing or not, and when the productive Coal-measures have been proved to be present over the entire royalty, or when the same bed has been found in three or more of the borings, thus giving the general dip of the strata. The quality of the coal, its thickness and character, can, as a general rule, be determined only by information obtained in mining.

CHAPTER VII

GENERAL STRATIGRAPHY (EXPOSED COALFIELDS)

The term 'coalfield' is applied to an area over or under which coal has been proved to exist, or is expected to occur at workable depths. When the coal-bearing strata are exposed at the surface, as is the case in all the more important coalfields of the world, the tract is called a 'visible' coalfield; if the coal strata are hidden beneath a formation differing in age from the one in which the coal occurs, such as that of Kent, the area is termed a 'concealed' coalfield. In many instances a coalfield is partly 'visible' and partly 'concealed.'

Those coalfields in which the coal-bearing strata appear at the surface have naturally been explored first, and it is from the examination of these coalfields that conclusions are drawn as to the probable character of the concealed areas. Beneath some areas a coalfield is suspected on geological grounds without any surface evidence of a coalfield in the vicinity.

A geological investigation of a coalfield consists in the determination of (1) the boundaries of the field; (2) the sequence exhibited by the coal-bearing strata; (3) the geological structure; (4) the quantity of coal and its quality.

Shape.—The boundaries of a coalfield are formed by rocks newer or older than the strata in which the coal occurs. When a coalfield is surrounded by newer formations, the relation of these to the coal-bearing strata, whether conformable or unconformable, must be ascertained. If conformable, then the coal-bearing sequence probably continues beneath them; but if unconformable, a part or even the whole of the productive measures may be absent.

The coalfield of South Staffordshire, for instance, is surrounded by two thick deposits of red strata, both barren of seams of coal. The one, so-called Permian—Keele and Hamstead beds (p. 212)—is conformable to the Coal-measures;

the other, Trias, is unconformable. Beneath the so-called Permian the Coal-measure sequence is intact, while the Triassic rocks rest at one place on a productive zone and at another on an unproductive zone. In a strict sense, the visible coalfield terminates at the outcrop of the barren Permian strata; but the so-called Permian is grouped with the coal-bearing strata, and thus forms part of the visible coalfield.

Similar instances can be given from many other coalfields where a coal-bearing formation is overlain by two groups of rocks very similar in character, the one resting conformably, the other unconformably, on the productive measures The determination of the relationship is evidently of vital importance, and is further exemplified in dealing with a concealed coalfield in a succeeding chapter.

Many coalfields are bordered by rocks, at once recognized as older than the coal-bearing formation. The strata containing the coal are surrounded by ancient crystalline rocks or by strata of such different types from those in which the coal occurs that they cannot possibly be mistaken for them. The boundaries of the coalfield in such cases are clearly defined by the outcrop of these very different rocks. The Sanquhar Coalfield (p. 283), is an excellent example.

In other coalfields the older strata possess many characters in common with the coal-bearing formation, and a closer examination is necessary to distinguish between them. For example, in the Warwickshire Coalfield black shales and sandstones of Carboniferous age rest on black shales and sandstones of Cambrian age, the lithological characters of the two being very similar—indeed, so similar are they that geologists were misled as to the difference in age, and it was only on fossil evidence that the disparity between the two formations was recognized. A study of the fossils and the stratigraphical relationship of the individual strata will, however, generally determine the age. Thus the presence of fossils only found in rocks older than the Carboniferous will at once show that the measures in which they occur antedate any coal-bearing strata (p. 30). The difference is also determined if one set of rocks contains pebbles of the underlying rocks, or if one group rests on the eroded and upturned edges of another group.

The shape of the coalfields, surrounded by rocks older than the Carboniferous, has been determined to some extent

by that of the eroded hollow in which the coal strata were laid down, of which the Douglas and Forest of Dean coalfields form good examples.

We now come to those coalfields whose configuration has been caused by pressure exerted subsequently to the deposition of the measures.

The shape and size of the Carboniferous coalfields in the Northern Hemisphere have been to a large extent determined by the great earth movement which supervened at the end of the Carboniferous period, and by others of a later period. During this period of disturbance the strata were folded in two directions at right angles to each other, with the result that the Carboniferous rocks occur mainly in basins. Since, as before stated, the productive portion of the Carboniferous formation is for the most part confined to the Middle, or Coal-measure, stage, it happens that the chief coal strata of the Northern Hemisphere occupy the centre of these basins, the Lower Carboniferous strata—generally unproductive—forming the margins.

The shape of the individual basins has been determined by the direction of the major folding. Most coalfields have either a longitudinal or latitudinal extension, according as the maximum pressure was exerted from the east and west or from the north and south, the orientation of the folds being naturally at right angles to that from which the pressure came. The coalfields of South Wales, Southern England, Northern France, and Belgium, for instance, extend latitudinally (often referred to as the Armorican direction of folding), since the chief pressure came from the south. The coalfields of Central and Northern England (Pennine folding) and of the United States have their longest diameters arranged longitudinally or at right angles to the pressure, which was exerted from the east. Within these major folds minor crumplings occur, and though a coalfield possesses as a whole a longitudinal direction, parts of it may extend at right angles to the general direction of folding.

In some cases the tangential pressure has affected the depression in which the coal-bearing strata were deposited, with the result that the original shape of the hollows has been wholly or in part obliterated or their outlines have been accentuated, thus giving a general orientation to several small basins, like the coalfields along the line of disturbance traversing the central valley of Scotland, the central plateau of France, those following the line of the

Alpine disturbance, and the Tertiary and Cretaceous coalfields of the Rocky Mountain region.

The result of pressure acting on any extensive deposits of coal-bearing or other rocks is to buckle them up into a number of anticlinal and synclinal folds. Subsequent denuding agencies, by removing large masses of strata from off the anticlines, have led to the formation of separated synclines or basins of Coal-measures, rimmed round by older formations, which have been laid bare by denudation. In this manner a once continuous sheet of coal-bearing strata has been broken up into distinct coalfields. The present disunited, but at one time connected, Lancashire and Yorkshire coalfields afford an excellent example of this arrangement.

Some coalfields, then, are bounded by newer rocks, others lie in the eroded hollows of older strata, and some owe their separate existence to earth movements. Not infrequently, however, the delineation of a coalfield has resulted from the combination of all three factors. Thus the Coal-measures of Coalbrookdale and Forest of Wyre were deposited in hollows in the older rocks; the newer Triassic strata cover them on the east, while their north and south orientation was, for the most part, outlined by post-Carboniferous but pre-Trias earth movements.

Again, in Central England we find at least five distinct coalfields. There is little doubt that the Carboniferous rocks composing them were once more or less continuous, and were deposited in a very irregular hollow denuded in strata older than the Carboniferous. By post-Carboniferous earth movements the once continuous but irregular sheet of strata was bent up into a number of folds trending generally north and south. Subsequent to or during the process of folding large masses of strata were removed, and one portion of the area was separated from another. The Triassic deposits were afterwards laid down on these folded and denuded strata, and further tend to disguise the original connection of the coalfields. These factors in the delineation of the coalfields of Central England also apply to many other coal-bearing regions.

In describing the general outlines of several coalfields distinctions must be made between those of which the boundaries represent the original margins of deposition, and those of which the boundaries are the result of earth movements supervening at a later date than the deposition

of the coal strata, and those in which the margins are composed of newer strata.

Sequence.—From dealing with the general form and outline of a coalfield we now pass to the study of the individual members which build it up—that is, to the character and arrangement of the strata associated with the seams of coal.

The strata of one coal-bearing formation may be similar to or differ from those of another. The same formation also frequently presents different phases of development from place to place, but generally a definite sequence occurs which can be taken as a type for a considerable area containing several coalfields, or the sequence may be quite local. Thus, the development of the Carboniferous rocks of the coalfields of South Wales and Somersetshire differs from the succession met with in the coalfields of Central England, and this again departs in many respects from the Carboniferous sequence in Northumberland and Scotland. The isolated Ingleton Coalfield, on the other hand, presents a local sequence.

The three chief coal-bearing regions, however, possess a common individuality—they are all of Carboniferous age, and may be regarded as representing one genus, each region forming a separate species, including several varieties.

The framework of the genus is in each case the same. It is made up of limestones, conglomerates, sandstones, shales, clays, and seams of coal; but these are differently arranged and possess individual characters for each of the three regions.

The methods employed to determine the individuality of a coal region is very clearly illustrated by the succession and character of the Coal-measure strata of the North Staffordshire Coalfield, a type species of the coalfields of Central England.

This coalfield belongs to the Coal-measure division of the Carboniferous formation. The Coal-measures rest conformably on a coarse pebbly sandstone in the north-east, but are unconformably overlain by or faulted against the newer Triassic formation. While, therefore, the base of the Coal-measures is clearly defined by the coarse pebbly sandstone, the summit lies concealed beneath the cover of red Triassic rocks.

The thickness of the Coal-measure strata capable of investigation amounts to over 7,000 feet, clearly divisible by the difference in character of the strata into two divisions

—a lower series, 5,000 feet thick, consisting of repeated alternations of grey sandstones and grey and black shales with numerous coal-seams and fireclays; and an upper series, consisting mainly of red sandstones and marls with a few thin coal-seams. The lower series is further subdivided into an inferior subgroup with few coals, and a superior subgroup with numerous seams of coal.

Neglecting the coal-seams, the strata belong to two very different types—the arenaceous group, including the sandstones and grits, and the argillaceous group of shales and clays. Owing to their superior hardness, the arenaceous strata generally occupy the elevated ground and give rise to conspicuous ridges, while the soft shales and clays form the gentle slopes or lie in the bottom of the valleys. The distinct surface contour of the sandstone ridges enables them to be picked out at the surface and followed for considerable distances; these features, indeed, are the chief landmarks of the geological surveyor mapping a coalfield. By laying down the position of these on his maps he is generally able to arrive at an accurate knowledge of the main structure of most coalfields.

Variability, both in thickness and lithological and physical characters, is the salient feature of the Coal-measure sandstones of the North Staffordshire Coalfield, as, indeed, it is of the sandstones of all ages associated with seams of coal. Some of the sandstones, however, maintain a nearly uniform thickness for considerable distances; others increase or diminish in certain definite directions. In North Staffordshire the tendency of the arenaceous rocks in the lower group is to increase in thickness northwards, and to dwindle away, and eventually die out entirely, to the south. Their character changes both laterally and vertically; the lateral change often takes place abruptly, a homogeneous sandstone at one spot passing in a short distance into a group of sandstones, shaly sandstones, and shales, and then reverting back again into an undivided sandstone. Generally speaking, the beds of sandstone become coarser in texture in the direction in which they increase in thickness—that is, to the north. In a vertical direction it is observed that the sandstones towards the base of the lower group are coarser in texture than those higher up in the sequence. An increased coarseness in texture among sandstones is commonly taken to indicate that they were laid down in the proximity of land, but many marked exceptions are known.

The shales and clays are much less liable to change in character and thickness than the sandstones. Three varieties of shales are met with. The commonest is a pale bluish-grey, laminated shale, more persistently developed in the upper part of the lower group. A jet-black, closely laminated variety also occurs in the lower portion, with or without an associated seam of coal. These shales are rare in the upper part, except in close association with seams of coal. Occasionally, and generally at definite horizons, though of no great lateral extension, bands of purple or reddish shales are developed in the lower series.

Like the shales, the clays vary in colour from black to grey, the latter being the most prevalent colour towards the summit of the lower group, where, however, certain bands assume a purple or reddish tinge.

From generalities we now pass to details, describing the character of individual beds, from below upwards, which are of economical value or of service to the geological surveyor.

The lower subgroup includes the strata between the coarse, pebbly sandstone (First Grit or Farewell Rock of the miner) at the base of the Coal-measures and a coal known as the 'Winpenny.' The general sequence in descending order is given in the following table:

	Thickness. Feet.	*Inches.*
WINPENNY COAL	—	—
Sandy beds	170	0
BRICKKILN COAL	—	—
Sandy beds, pottery marl at base	20	0
SILVER MINE COAL	3	0
Sandy beds and shale	90	0
CANNEL ROW COAL	3	0
Sandy beds and shale	90	0
THIN COALS	—	—
Sandstones, ganister, and dark shales	520	0
Thin coal	1	8
Shales (marine shells at base)	130	0
CRABTREE OR FOUR FEET COAL	4	0
Pebbly grit and shale	61	0
Small coal	1	0
Dark shales	59	0
LITTLE ROW OR TWO FEET COAL	2	3
Purple sandy shales	47	0
Dark shales	100	0
COAL	1	0
Purple shales	5	0
Coarse pebbly sandstone (First Grit)	—	—

The diagnostic characters of this sequence are the purple shales below the Little Row Coal, the pebbly grit below the Crabtree Coal and the shales with marine shells above it, the barren measures between this coal and the Cannel Row, and the sandy beds forming the floor of the Winpenny Coal. This sequence also holds good for some of the other Midland coalfields where the group is developed and a sufficient examination is made, while throughout the Midlands the roof-shale of a coal similar in position and character to the Crabtree Coal invariably contains a marine fauna (p. 55). The upper subgroup includes the strata between the Winpenny Coal and the red marls at the base of the upper division. A subdivision, based on the character of the coals, and to some extent on the nature of the strata and fossils, has been made at the horizon of the Ash Coal. Owing to a gradual increase in the collective thickness of the measures northwards, and a rapid diminution to the east, the thicknesses given in the following table represent only an approximate average thickness throughout the coalfield:

	Thickness. Feet.	Inches.
Shales, sandstone, and thin coals	150	0
GIN MINE OR TWIST COAL -	3	0
Shales, sandstones, thin coals, and ironstones -	540	0
MOSS OR MOSSFIELD COAL - -	5	0
Shales and sandstone (Yard Coal Rock)	220	0
YARD COAL	6	0
Shales and sandstones (Ten Feet Rock)	—	—
TEN FEET COAL	7	0
Shales and sandstones	300	0
BOWLING ALLEY COAL -	4	0
Shales and some sandstone	80	0
HOLLY LANE COAL	4	0
Shales	75	0
HARD MINE COAL -	4	0
Shale, sandstone (Bambury Rock) -	350	0
SEVEN FEET BAMBURY COAL -	4	6
Shale and sandstone (Cockshead Rock)	150	0
EIGHT FEET BAMBURY OR COCKSHEAD COAL	8	0
Sandstone, shales, and thin coals	260	0
BULLHURST COAL	5	0

The chief components of this subgroup are the coals, but their character and development at any one horizon must be regarded for the present as varietal and not specific—that is to say, the coals belong to the North Staffordshire variety, though it may be found that some of them are

correlative with coals occupying approximately the same position in the Midland sequence, for the best and most persistent coals throughout the Midlands are found to occur at about this horizon in the upper division of the Carboniferous strata.

In the same manner the sandstone members are variable, though, as in other Midland coalfields, they are more persistently developed than in the upper subgroup. The Ten-Feet Rock can be traced regularly throughout the district, but is apt to become split up by shale bands in some places. The two Bambury rocks and the Yard Rock, though less conspicuous at the surface, are recognizable in most shaft sections. Each of these sandstones sometimes rests directly on the coal from which it takes its name, or is separated from it by several feet of shale and clay.

The beds of shale unquestionably form the truest index of horizons, but this arises, not from any distinctive lithological characters or the development of one kind of shale at any definite horizon, but from the fossils found in them (pp. 48-50).

The sequence in the upper subgroup is given in the following table:

	Thickness. Feet.	*Inches.*
Shales, thin limestones, and Black Band ironstones	360	0
Bassey Mine Coal	2–6	0
Shales and clays	45	0
Peacock Coal	2	10
Grey shales, sandstones, and thin coals	105	0
Great Row Coal	8	0
Clay, shales, ironstones, and thin coals	66	0
Cannel Row Coal	5	0
Sandstones, shales, clays, and ironstones	390	0
Bay Coal	2	1
Rock	21	0
Shales and ironstones	30	0
Knowles or Winghay Coal	6	0
Shale, clay, and sandstone	300	0
Ash or Rowhurst Coal	6–10	0

Varietal rather than specific characters predominate in this subgroup. Thus the number and value of the Black Band ironstones above the Bassey Mine Coal distinguishes the North Staffordshire Coalfield from any other in the Midland Province, where they are either altogether absent or are but feebly developed. The thin bands of limestone, again, though prevalent in the other coalfields towards the

summit of the subgroup, are not always present. Below the Bassey Mine Coal the absence of thick-bedded, persistent sandstones may be noted.

Reviewing the lithological characters of the upper group as a whole it is seen that they are ill-defined and form uncertain, though locally useful, guides. The variability in the lithological character, thickness, and development of the sandstones and shales of the Pottery Coalfield is also characteristic of other coalfields, and has always been taken into account. The correct determination of the variety presented by a local sequence is of much greater practical value than broad generalizations based on imperfect knowledge.

Three very distinct groups of Coal-measure strata, known in ascending order as the Etruria Marl, Newcastle, and Keele groups, succeed the Lower Division. These three groups are typically developed in the North Staffordshire Coalfield, and, where not denuded, are met with in the other Midland coalfields. We have therefore to deal with specific and not generic characters.

The Etruria Marl Group consists of a great thickness of purple and red unstratified marls. Especially characteristic are some bands of green grit occurring at several horizons. These green grits are largely made up of fragments of igneous material set in a matrix of the same nature, and containing pieces of other rocks. The Newcastle Group consists of grey sandstones and grey shales, with three or four thin seams of coal, while the Keele Group is composed of red sandstones and red marls, without any bands of green grit. Thin limestones with *Spirorbis* are common to the three groups.

Geological Structure.—The strata associated with the seams of coal were laid down approximately horizontally, but there are few coalfields in which the original position of the strata has been maintained. On the contrary, they are found lying at all angles, often nearly vertical, and in some cases the beds have been completely overturned, and the order in which they were originally deposited is reversed, the oldest being at the top and the newest at the bottom. This structure is splendidly illustrated along the Pembrokeshire coast.

Earth pressure, and more rarely igneous intrusions, have been the chief cause in effecting the change from the original position. In accommodating themselves to the pressure

the beds were folded on each other, were fractured (faulted), and one portion depressed or elevated relatively to another. In most faulted and folded regions it is necessary to recog-

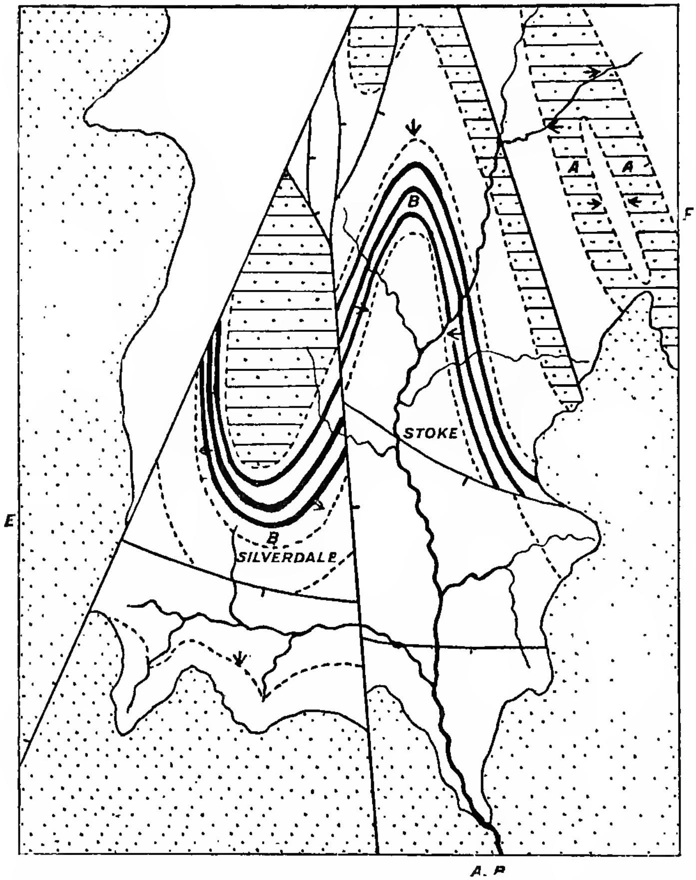


FIG. 8.—MAP TO ILLUSTRATE THE STRUCTURE OF AN EXPOSED COALFIELD.

In N.E., lower measures are line-stippled; chief coal-bearing strata shown by curved thick lines; newer formations by open stipple. Arrows indicate the direction of dip.

nize faults due to accommodation, when strata are undergoing compression, and faults due to relief from pressure.

Many coalfields, as we have stated, owe their shape to pressure exerted in one or more directions. The same

pressure has a powerful effect on the internal structure of a coalfield by throwing the strata into folds, or causing them to break across and become faulted. Folding and faulting are sometimes beneficial, but more often adverse, to coal-mining. They may, for instance, bring a seam of coal nearer to the surface than it would otherwise have been; or in some cases, again, faults depress a whole number of seams beyond reach. It is thus evident that a knowledge of the amount of folding and faulting to which a coalfield has been subjected is of great importance to the coal-miner.

Folds.—As an example of the general principles included in the study of the folding and faulting of a coalfield, the North Staffordshire Coalfield—represented to some extent diagrammatically in Fig. 8—is taken, since to understand the structure of a coalfield a knowledge of the strata involved is essential.

If the bed of coarse, hard, pebbly sandstone (*A*, Fig. 8) be followed from south-east to north-west, it is found highly inclined to the west. Crossing the outcrop and going eastwards, the same sandstone crops out again, but is now highly inclined to the east, reappearing at the surface a little farther east, with again a westerly dip. We have here an example of a narrow trough, or syncline, formed by the band of pebbly sandstone, and enclosing the strata of the Lower Division of the Coal-measures in the centre of the trough. By tracing the sandstone round this trough the axis is found to trend west of north, and is found more highly inclined on the western side of the basin than on the eastern side.

Employing the same methods, but in this case taking the outcrop of the Bassey Mine Coal (*B*, Fig. 8) as a guide, it is found that the Coal-measures of this coalfield are thrown into two easily recognized folds.

In the centre of the coalfield the Bassey Mine Coal lies in a trough, as indicated by the dip arrows. The axis of the syncline trends nearly north and south. On tracing the outcrop of the lower coals and their associated sandstones round the trough, it is seen that the fold widens out in the south and comes together in the north, the seams rising one after another to the surface. In the south, on the contrary, the seams get deeper and deeper.

North-east of Silverdale the Bassey Mine Coal, as shown by the arrows on the map, dips to the south-east, but

inclines south-west, a little to the north-west of the same locality. This is an example of a ridge fold or anticline as opposed to the trough fold or syncline assumed by the Coal-measures in the central parts of the coalfield. The axis of the anticline trends a little north of east, and rises to the north, so that lower and lower measures come to the surface in this direction as they did in the syncline. Mining on the anticline shows that the seams are highly inclined near the surface, but flatten out after a certain depth on the east and west flanks. The fold has thus the shape of an inverted vase.

The direction in which coal-workings are carried on is greatly influenced by the foldings to which the strata have been subjected. Mining has naturally proceeded along or near the outcrop of the seams of coal round the central syncline and western anticline, the deeper seams still remaining untouched towards the centre of the syncline,

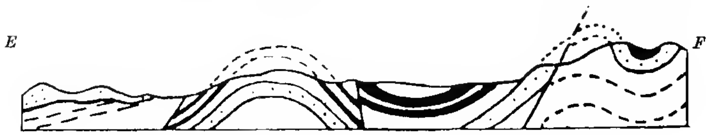


FIG. 9.—SECTION BETWEEN *E* AND *F* ON FIG. 8, P. 76.

where the Keele Group is at the surface. In the anticlinal region, on the other hand, mining necessarily proceeds outwards to the east, south, and west, since the core of the fold is only occupied by the lowest measures, the Seven Feet Bambury Rock occupying the crest. The determination of the position of a bed, whether occupying the crest of an anticline or the centre of a syncline, is therefore of great importance.

The open folding in the type of coalfield just described is common in the coalfields of Great Britain generally.

In Pembrokeshire, Pennsylvania, and Northern France earth movement has resulted in far more complex crumplings of the strata, and surface observations are often altogether misleading as to the underground structure. A number of higher seams, for instance, are violently contorted at the centre of a compressed syncline of the vase-shaped structure, and become almost horizontal at great depths; on the other hand, in an inverted vase-shaped anticline, in a region of intense folding, the upper strata are less crumpled

and compressed than the lower, the amount of compression depending upon the restricted space into which the rocks had to accommodate themselves.

After the nature and amount of folding have been determined, the next point to settle is the period or periods at which it took place.

In North Staffordshire there are grounds for supposing the earth movement was taking place during the deposition of the Coal-measures, since, to whatever extent the great variability in the thickness of the individual strata may be attributed to excess of material and the power of the transporting agency, there must have been depression to allow the sediments to accumulate. As there is no reason to suppose that the strata immediately below were eroded into irregular hollows—in fact, the evidence rather points the other way—the irregular deposition of the sediment can reasonably be attributed, at least in part, to contemporaneous and local earth movement. To what extent such contemporaneous depression and elevation look place is unknown, but it is certain that the chief folding occurred after the deposition of the highest strata of the Keele Group, and that the crests of the folds were extensively denuded before the deposition of the succeeding rocks (Trias).

These newer (Triassic) strata lie almost horizontal, but in the south-east and south-west there is evidence that they were folded along the same lines as the Carboniferous rocks.

A later fold superimposed on an earlier one is known as a posthumous fold.

Faults.—Relief from pressure attained by folding is usually accompanied or followed by faulting.

Faults ('heaves,' 'troubles') are normal or reverse—normal when newer beds have been depressed relatively to the older strata, and reverse when older beds have been thrust over newer. In a normal fault newer strata, in a reverse fault older strata, are found on the side to which the fault is inclined. Normal faulting occurs when strata have to accommodate themselves to increased space, reverse faulting when strata are compressed into a space less than their original horizontal extension.

North Staffordshire affords an excellent field for the study of normal faulting. The direction of the main or 'master' faults can be easily determined at the surface, and their throw approximately made out; but there are

many smaller faults the existence of which has only been made known by mining.

The type region, however, affords few examples of reverse faults, but they are of frequent occurrence in the Pembrokeshire Coalfield, in the coalfields of Northern France, and in the anthracite fields in Pennsylvania, and, in fact, in all regions where earth movement has been excessive. They are common in many coalfields of Carboniferous age, and also in the Tertiary formation of America, Japan, and other countries along the lines of maximum disturbance.

A fault can often be detected at the surface by its bringing together beds of different horizons in the sequence. Sometimes, though not frequently, the actual fracture is visible. The existence of a fault is also suspected from an abrupt discontinuity in the surface features.

The chief points to determine about a fault are the direction, the inclination, the amount of throw, and the age.

The fault shown to the east of Silverdale (Fig. 8, p. 76) brings a high horizon of the Keele Group on the east within a short distance of a much lower horizon of the same group on the west. Again, a little farther to the north, Keele beds are in contact with the Newcastle Group, and to the west of Stoke the Keele Group comes in contact with the Bassey Mine Coal. By connecting the various points at which these abnormal junctions of strata are seen, we obtain the north and south direction of the fault. This method of determining the direction of a fault requires that the points of observation shall not be far apart, as the same juxtaposition of beds can arise by another fault having a different direction.

The inclination of a fault plane from the vertical is termed the 'hade' or 'underlie.' 'Hade' is therefore the complement of 'dip,' which is measured from the horizontal. Strictly speaking, a low hade fault is one highly inclined from the horizontal, while a low hade fault—*i.e.*, horizontal thrust faults, which are frequent in Pembrokeshire—possesses no dip. Not infrequently, however, the term 'low-hading fault' is incorrectly applied to one which makes a high angle with the vertical, and should be called a 'high-hading fault.' In coal-mining the general practice is to speak of a fault plane as being highly inclined or as having a high dip when the hade is low, and as being gently inclined or as having a low dip when the hade is great. The term 'hade' is seldom used by coal-miners, and it would be

better to restrict it to metalliferous mining, and in coal-mining to state the amount of inclination in degrees measured from the horizontal, since this is the idea generally meant to be conveyed. The hade in the upper workings of a mine sometimes differs from that in the lower workings (Fig. 10).

Fault planes are frequently curved, and if a distinct inclination of the fault in the direction of the working face were observable, the fault encountered may still be a downthrow with respect to the seam being worked, and the seam sought for occur at a lower level on the other side of the fault.

The amount of throw, either downthrow or upthrow, is the vertical distance that a bed has been displaced. The amount varies from a few inches to several hundred feet. Underground the amount of throw can be accurately

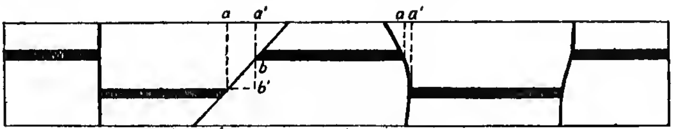


Fig. 10.—To illustrate Various Hades in Faults.

measured, but at the surface an approximate estimate is usually all that can be attained.

The apparent horizontal displacement of beds by a fault as seen on the surface of the ground is termed the 'lateral shift' or 'shift,' the intervening space (*a–a'*, Fig. 10) being known as the barren ground or 'want' of the fault. The width of the barren ground varies with the hade and amount of throw. Many geological plans give the width of the 'want' by showing in separate colour the surface position, its position on the upthrow side and on the downthrow side, as in the illustration.

To the west of Stoke the fault previously mentioned as bringing Keele beds against the Bassey Mine Coal has a throw estimated at over 400 yards, while the fault shown to the west of Silverdale possesses a throw of over 700 yards in one locality.

In mine-workings the amount of throw is usually proved by driving or boring across a fault until a seam is met with on the other side. The limited space for observation underground frequently renders it difficult to decide what

method is best to reach the seam across the fault. For instance, a colliery working the Great Row Coal (p. 74), and following it underground to the west of Stoke, encounters a fault bringing red marls against the coal. Boring up and down in these red marls proves that they are the red marls associated with the Red Mine Ironstone some distance above the Bassey Mine Coal. The fault is therefore a downthrow to the west.

In another case a fault met with in the workings in the Ash Coal (p. 74) brings this seam against shales containing the peculiar marine organisms only met with in the shales a few feet below the Gin Mine Coal. The approximate throw and its direction can thus be determined.

After driving a short distance across a fault, a bed may be met with containing fossils, occurring in a band known in the proved coalfield to lie 300 feet above the seam being worked. Farther, this fossiliferous band lies a few feet below a bed of sandstone. If, therefore, on continuing the cross-cut in the direction of dip this sandstone is met with, there is the strongest evidence for regarding the fault as a downthrow in respect to the coal being worked, and that the throw approaches 300 feet. The seam sought for will in this case be found 300 feet below the level of the same seam at the working face where the fault was encountered.

A fossiliferous bed containing very distinctive fossils is of rare occurrence. Two beds, however, may occur, one above and one below a seam of coal, or they may both be above or below the coal, the fossils of both being identical. These two fossiliferous bands will, however, afford good evidence of position in the sequence. If, for example, on crossing a fault a coal-seam is met with, and then by boring up and down the coal is found to occupy a position between these two fossiliferous beds, or if both lie above or both below the coal, then the identity of the seam receives strong confirmation.

A distinctive fossiliferous bed in an area of normal or reverse faulting will satisfactorily prove both the character and amount of throw of a fault. Where two or more fossiliferous bands containing similar fossils are present, caution must be exercised in the determination of the amount of throw of a fault where both normal and reverse faults occur. In this case other beds will have to be taken into account, and their relative order of occurrence noted.

Joints.—The divisional planes called ‘joints’ traversing a seam of coal and the associated strata at right angles to the

bedding are the result of mechanical strain due to pressure exerted subsequently to deposition. They are frequently developed in districts where folding and faulting are slight, and are invariably present in disturbed regions.

Joints in coal can be recognized by the bright glistening planes traversing the dull layers ('mineral charcoal') at right angles. Coal-seams are commonly crossed by two sets of joints known as 'cleat' (face) and 'end,' which extend for great distances as well as maintaining a general direction in any particular coalfield. In the North of England, for instance, the cleat runs approximately north and south.

The working of a coal is largely determined by the direction of the jointing. Main roads run parallel to the cleat, while 'bords' are driven at right angles to it. In working coal on the 'long wall' system, the face, when parallel to the cleat, is said to be 'on the end'; when perpendicular to the cleat, 'on the face'; and when in another direction, the face is termed 'half-on.'

Fault Systems.—From dealing with individual faults we now pass to the study of faults as members of one or more systems.

In the type region two or more systems are displayed; in one system the faults have a meridional trend, in the other a latitudinal trend. In this region the two systems have been formed simultaneously, and since their throw is greatest in the strata of the Carboniferous formation, they are mainly of pre-Triassic age, though displacement along both lines has taken place subsequently to the deposition of the unconformable covering strata.

In other coalfields it is possible to definitely prove that one system of faulting is older than the other, as in the Cumberland Coalfield.

Taking the Carboniferous coalfields of Europe as a whole, it is found that the chief faults crossing them were formed, and had attained their maximum development, before the deposition of the Secondary formations, though subsequent movement has in some cases taken place along the same lines. Thus in the type region the fault of 700 yards downthrow to the west, bounding the coalfield on the west, has nothing like the same amount of throw in the Trias. If it did possess this amount of throw, the upper and not the lower members of the system would be in contact with the Coal-measures. The east and west fault south of Stoke, with a downthrow south of nearly 90 yards, does not much

exceed 50 yards throw in the Trias. Many still more striking examples of the difference in the amount of throw of faults in the older rocks and in the overlying newer strata occur in other coalfields. Generally speaking, the throw in the newer formations is less than in the older, but occasionally it is equal in amount and sometimes greater.

Faulting, like folding, has in many cases been completed before the deposition of the newer strata, and because the younger formations are but little fractured it does not hold that the older rocks upon which they rest will be found equally undisturbed. As a general rule, however, if the newer strata forming the surface formations are very much faulted the older strata below will be found disturbed to a much greater extent.

Unconformity.—The geological structure of a coalfield may have been formed during the deposition of the coal-bearing strata, or it may have resulted from subsequent disturbance which has modified the original structure. It is often of importance to determine whether a period of movement and contemporaneous erosion on an extensive scale took place while the coal-bearing strata were being laid down, or whether the disturbance is of later date.

In North Staffordshire the Keele Group was at one time considered to rest unconformably on the grey productive measures, and for this reason was grouped with the Permian Formation. Along the western boundary of the coalfield it was thought that in one locality, the whole of the Newcastle Group, Etruria Marl Group, and the grey productive measures down to the Great Row Coal, had been denuded away before the Keele Group of sandstones and marls was deposited. In other words, considerably over 1,500 feet of Carboniferous strata had been denuded before the deposition of the Keele Group had commenced (p. 159). A detailed survey of the coalfield shows, however, that the Keele Group invariably succeeds the Newcastle sandstones and marls, and whenever the Keele beds are in juxtaposition with any lower strata they are found to have been brought into this position by faulting. The apparent unconformity along the western boundary is therefore an anomalous condition, and it appears still more striking when it is found that a short distance away the normal succession is present. Either the red strata along the western margin do not belong to the Keele Group, or, if they do, then their present position is due to faulting, a conclusion strengthened

by the knowledge that throughout the Midlands the Keele Group is invariably conformable to the Newcastle sandstones or their equivalent. Local information and detailed mapping could alone have settled the conformable relationship of the Keele Group to the Coal-measures in North Staffordshire.

In dealing with concealed coalfields, the determination of the relationship of the different divisions and groups of the Coal-measures is of great practical importance. In several coalfields geologists are still debating as to what extent inter-Carboniferous movement and denudation have taken place.

Supply.—Estimates of the amount of available coal contained in a visible coalfield only partially worked must be regarded as merely approximations at the best. The allowances made for the waste in working, the amount of coal left to maintain shafts, for the support of buildings, railways, canals, and rivers, and for the barriers between royalties and properties vary greatly from district to district. Again, in many coalfields the best seams lie towards the bottom of a great thickness of strata, and, except near their outcrops, lie beyond the depth at which it is at present considered practical to work them. In this country the maximum depth at which coal is considered workable is 4,000 feet, and on the Continent is about 4,900 feet.

The minimum thickness of a coal-seam that it will pay to work depends upon local circumstances, such as demand, price, and cost in working. In this country 1 foot is the minimum thickness adopted by the Royal Commissioners in their calculations in the Report on Coal Supply for 1905, and this is taken in the description of the different British coalfields in succeeding chapters. One foot thick of coal yields 900,000 tons per square mile, or 1,500 tons per statute acre.

Many of the problems connected with the determination of the total available supply of any coalfield belong essentially to the province of the mining engineer, but the geologist is called upon to estimate the depths of seams, and the direction and amount of throw of faults in unproved ground, together with other essentially geological problems.

In North Staffordshire, for example, the centre of the major syncline is occupied by the upper barren division of the Coal-measures. If the thickness of the groups making up this division can be ascertained and their outcrops laid

down on a map, it will be possible to estimate the depth to the workable seams under the area occupied by each of these groups. Mining has not proved the thickness of the individual groups, which is ascertainable, however, by an examination of the surface outcrops. Thus a shaft commencing towards the summit of the Etruria Marl Group would reach the Bassey Mine Coal at a depth between 1,100 and 1,500 feet, and the Ash Coal between 1,800 and 2,400 feet. The same seams are reached from 300 to 400 feet lower by a shaft starting near the summit of the Newcastle Group, while at least 700 feet more must be added for the depths to these seams where the Keele Group passes under the Trias, as it does along the southern margin of the coalfield. Many of the lower and best seams below the Ash Coal would, therefore, here exceed the limit (4,000 feet) of workable depth. In their estimation for 1905 the Royal Commissioners regarded the North Staffordshire coals as existing at workable depths half-way across the outcrop of the Keele Group.

Cover.—Where the Coal-measures of North Staffordshire sink below or are faulted against the Triassic strata, the visible coalfield passes into the category of a concealed coalfield.

As previously stated, the relationship of the Trias to the Coal-measures is one of complete unconformity. At one place on the east of the coalfield the practically horizontal Triassic rocks rest on the folded, highly inclined, and greatly denuded Lower Carboniferous strata, at another place on the lower division of the Coal-measures, and at another on the Keele Group.

The red rocks were evidently deposited in hollows worn in the Carboniferous strata, thus levelling up the older inequalities, and in other cases were banked against the steep slopes of the highly inclined Carboniferous strata. In such cases as this the junction of the two sets of strata has the appearance of a fault. This is especially deceptive where the red marls of the upper Trias overlap and successively hide up the subdivisions of the lower Trias until they abut against the Carboniferous strata. When in contact with the harder members of the Carboniferous rocks, the red marls, partly owing to slip, appear crumpled, and simulate faulted strata. In this particular case it appears as if a fault, having a throw equal in amount to the thickness of the Lower Trias, had brought the red marls against the Carboniferous formation.

When newer unconformable strata are faulted against older rocks, it is often impossible to calculate the amount of throw, since it is not always practicable to determine to what extent the juxtaposition is due to unconformity or to faulting. Thus, along the western margin of the North Staffordshire Coalfield the Trias at one spot is faulted against Middle Coal-measures, and at another against the Keele Group, but this does not necessarily imply that the fault possesses a greater throw in the first case than in the latter. By neglecting to make allowances for unconformity, faults bringing newer strata against the Carboniferous rocks have often been assigned a great magnitude of throw.

Calculations have often to be made as to the thickness of the Triassic rocks based on their inclination observable at the surface. This can be more or less satisfactorily done in the case of the Keuper Marls, in which bedding planes are on the whole clearly developed. In ascertaining the amount and direction of dip in the red sandstones and conglomerates which form the greater part of the Lower Trias, and which are usually met with around the margins of the English coalfields, care is necessary to distinguish between 'true' and 'false' bedding.

Irregular bedding, where the individual laminæ are not parallel to the surfaces of the greater bed in which they occur, but where the laminæ in one bed slope at very different angles or in different directions to those in the bed above or below, is a common characteristic of Triassic sandstones. False bedding on a larger scale occurs where one bed has been deposited on the sloping and worn surface of another.

Rough approximations as to the thickness of the Trias sandstones are all that can usually be made, and these are frequently very wide of the mark.

Geological Maps.—The outcrops of the more important strata, seams of coal, and faults are generally shown on the geological maps issued by most Governments. In this country the maps are published on the scale of 1 inch and 6 inches to the mile, but in foreign countries maps on the larger scale are rarely available. In the Colonies the scale adopted is usually less than 1 inch to the mile.

In the case of the 1-inch maps of the Geological Survey of the United Kingdom, two editions are published for

many of the coalfields. One of these shows the superficial deposits, and the other the solid rocks only. On a solid map the lines of visible outcrop of the solid formations are continued under the superficial deposits. The accuracy of these lines depends largely upon the amount of evidence obtained in mining.

CHAPTER VIII

GENERAL STRATIGRAPHY (CONCEALED COALFIELDS)

In Europe the visible coalfields have been worked out to a considerable extent, and it is necessary for collieries of long standing to seek fresh royalties outside the visible coalfields in which most of the coal has been leased. Explorations in search of coal are, in consequence, extended into regions where coal-bearing strata are thought to exist beneath the newer formations. Such explorations are to a great extent confined to the margins of the visible coalfields, but several attempts have been made, or are now in progress, to prove the existence of buried coalfields remote from any known workings. Especially is this the case in Central England, and also in the south-eastern counties. In Northern France, Belgium, Holland, and along the borders of Alsace-Lorraine, these experimental trials for coal are also being conducted on a considerable scale.

In an exposed coalfield many of the geological problems are of a comparatively simple nature. From observations made at the surface with the help of the knowledge obtained in mining the general structure of an exposed coalfield and many of its details are satisfactorily determined.

In the choice of a site for a new sinking or boring in a concealed coalfield, and in the interpretation to be placed on the result obtained, the prospector needs a wider knowledge of geology than in the case of an exposed coalfield.

As an example of a buried coalfield we take the area represented in Fig. 11. This illustrates in a diagrammatic and simplified form the southern half of the Midland coal-basin of Central England at a time when the Coal-measures on the east and west were exposed at the surface much as they are now, but before denudation had stripped the Triassic cover from off the South Staffordshire Coalfield.

Observations made at the surface and underground over

the visible coalfields on the east and west indicate that the coal strata, consisting of the Middle and Upper Coal-measures (p. 157), slope inwards towards the centre of the region occupied by the newer formations. The inference is therefore drawn that the coal-seams that crop out in the east are prolonged underground, and rise again to the surface in the western coalfield.

The choice of a site for the commencement of a series of experimental borings or trial shafts is controlled by ex-

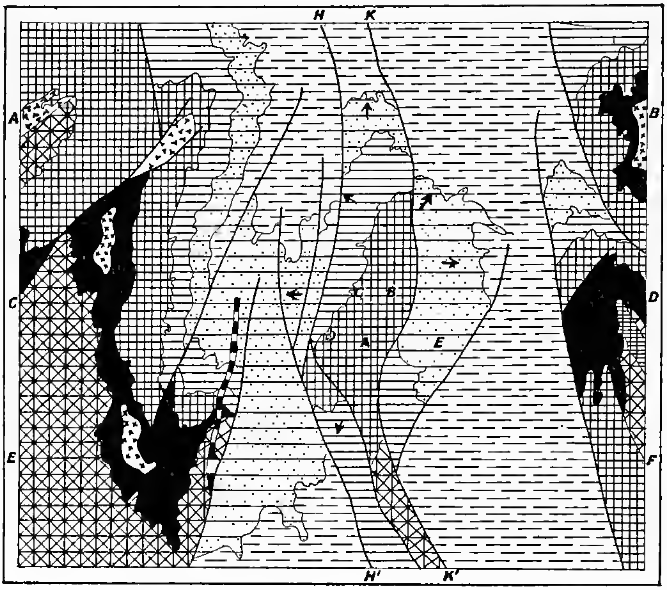


FIG. 11.—MAP TO ILLUSTRATE A CONCEALED COALFIELD.

An anticline of newer rocks overlying Coal-measures traverses the central area from north to south, coal-bearing strata (black) crop out to the east and west. Lettering in margins refers to sections, p. 95.

perience gained in the marginal coalfields and on the geological structure of the district as a whole, including an acquaintance with the formations newer than those bearing the coal. The chief points to ascertain before commencing work in an unproved area are: (1) The sequence of the Coal-measures in the neighbouring visible coalfield; (2) the relation of these Coal-measures to the older formations; (3) the character and thickness of the covering strata and their relation to the productive measures.

Sequence.—The Coal-measure sequence in the exposed coalfields consists essentially of a lower division of grey strata (Middle Coal-measures) containing several workable seams of coal, and of an upper division of red strata with no workable seams. In this sequence definite positions can be fixed by the presence of thin bands or groups of strata possessing distinctive lithological or palæontological characters which are found to closely resemble those appertaining to the type region of North Staffordshire (p. 159), though the individual groups differ to some extent from the type region. The relation of the red upper division of the Coal-measures to the lower grey division is one of strict conformity. The grey measures are succeeded by the Etruria Marls, these by the representative of the Newcastle Group (here called Halesowen Sandstone Group), and this in turn by the Keele Group. In no instance do the Keele or Newcastle beds rest directly on the grey productive measures, and when apparently found to do so the juxtaposition is demonstrably a fault.

In tracing the Coal-measure strata from north to south, however, it is found that first the lower division ends off against rocks older than the Coal-measures; and, again, farther south, that one group after another of the upper division terminates against a bank or ridge of older rocks, until along the southern margins of the exposed coalfields the Keele Group rests directly on strata of Cambrian age. This relation to the older strata is not to be confounded with an unconformity within the Coal-measure sequence, but as an example of conformable overlap on the group of Coal-measures and of unconformable overlap of Coal-measures on to Cambrian.

The covering up of a lower member of the Coal-measures by a higher may be regarded in the same way as an illustration of progressive overlap in the direction of an old shore line, and as indicating the gradual sinking of the basin and its successive infilling with the various Coal-measure sediments. In this case the uselessness of exploring for coal along the southern margins is obvious, since the latest strata deposited do not contain workable coals and the lower members are absent in the neighbourhood of the overlap.

The general sequence of the Coal-measures, as before stated, conforms to the North Staffordshire type; but while, except in thickness, there is the closest similarity between

the three groups of the upper red-and-grey division, the lower grey division presents several local variations, and that of the eastern coalfield is somewhat different to that of the western field.

The grey Coal-measures in the three coalfields figured show a considerable diminution in thickness in comparison with the type region, and it is doubtful to what extent the lowest measures are developed, if they occur at all. In the north-eastern field the thickness of the measures amounts to about 1,500 feet, which has decreased to under 1,000 feet in the south-eastern field. In the western field the total thickness of productive measures does not amount to more than 500 feet.

The change in the thickness of the strata is accompanied by a change in the thickness and number of the seams. Thus, in the north-eastern field the seams rarely exceed 7 feet in thickness, and about a dozen are workable. In the south two or more of these seams unite to form one bed of coal between 15 and 16 feet thick, but both this thick seam and the others rapidly deteriorate and become valueless towards the southern extremity of the coalfield. No thick seams occur in the western field.

One portion of the productive measures is scarcely recognizable from another by the lithological characters. A group of red marls is commonly present above a persistent seam about 1,000 feet above the thick seam. A band of shale and ironstone with marine shells occurs a short distance above a thin seam of coal in the west. We shall, however, consider that the information collected about these marine beds is too indefinite to enable them to serve as absolutely reliable guides other than indicating the presence of the productive measures.

Associated with the grey measures in the north-eastern and western coalfields a crystalline rock recognized as a basalt lies parallel with the bedding planes in the east and cuts across them in the west (Fig. 12, p. 95). In the latter case there can be no doubt that the igneous rock is of later date than the Coal-measures, but the age of the igneous rock in the north-eastern coalfield must be determined by observation of its effect on the beds immediately above and below it. If it alters or bakes the beds above and those below, the intrusion is obviously of newer date; but if it only alters the underlying bed, it is contemporaneous with the deposition of the strata. In many cases, however, it is

difficult to detect any signs of alteration either by contemporaneous or intrusive igneous rocks. When the igneous rock is found in contact with a coal-seam, it usually causes the coal to become anthracitized, coked, and in many cases renders the seam worthless. It is important in this area to distinguish between an igneous rock contemporaneous with or intrusive into the Coal-measures from one of much older date than the Carboniferous formations. Examples occur in the south-eastern coalfield where igneous rocks penetrating pre-Carboniferous rocks had obviously consolidated and had been denuded before the Coal-measures were deposited. Petrologically the two types of igneous rocks are distinct.

Carboniferous and post-Carboniferous igneous rocks generally present, except near their selvedge margins, crystals of felspar, augite, and olivine in a more or less fresh state. In the pre-Carboniferous igneous rocks the olivine is found much serpentinized, and several minerals—chlorite, calcite, and epidote—resulting from decomposition are developed. The central portions of an igneous rock are, as a rule, less decomposed than the margins, and in the determination of the age by mineral composition comparisons should be made between the undecomposed portions.

In the eastern coalfield an igneous rock, termed 'diorite,' perceptibly alters the Cambrian shales and quartzites when in contact with them; but while the Coal-measures rest on its eroded edges, they contain rounded pebbles of the igneous rock, and are not in the slightest degree disturbed or altered, even when in actual contact. This is clearly, then, an igneous rock of later date than the Cambrian, but older than the Coal-measures or than the igneous material occasionally met with in the Coal-measures, and to which these vastly older igneous rocks bear some resemblance.

Igneous dykes are frequently vertical, or they cut across the strata at an oblique angle. In the former case it is obvious that a boring gives a very exaggerated thickness to a dyke, and also makes a seam of coal beneath it appear to lie at a much greater depth from the surface than it really does.

Igneous material, when not a contemporaneous flow, may have come up along fissures as dykes or as necks. The latter are vertical pipes filled with volcanic material, often

descending to great depths, but are absent in the area under description, and in many other coalfields have been proved to be far less common than formerly supposed, though examples occur in Scotland.

Relation to Older Formations.—In the type region of North Staffordshire the productive measures rest conformably on the sedimentary rocks belonging to the Lower Carboniferous formation. Wherever the base of the Coal-measures is seen, the bed immediately below consists of a coarse, pebbly sandstone, which can be proved by fossil evidence to belong to the Carboniferous formation—that is, to the same formation as that in which the coal occurs—but to have been deposited at an earlier stage of the Carboniferous period.

The Coal-measures shown on the map (Fig. 11, p. 90) rest on very different rocks: those of the south-eastern coalfield lie on strata consisting of quartzitic grits, black shales, or igneous rocks, and those of the western coalfield on red sandstone. In the former case the fossils prove that the black shales and quartzites, though in some respects resembling the overlying Coal-measures, are of Cambrian age; in the western coalfields the fossils of the red sandstones show them to be of Devonian (or Old Red Sandstone) age (table, p. 31). At another place the Coal-measures rest on limestones and shales containing Silurian fossils.

These older pre-Carboniferous rocks appear either as promontories or bays round which the Carboniferous sediments were unevenly deposited during the Coal-measure period. The surface of the older rocks when in contact with the Coal-measures is very irregular, but on the whole may be regarded as forming two uneven platforms—an eastern and a western one—on which the Coal-measure strata were accumulated. These platforms descend somewhat abruptly, to the east and west respectively, into the hollows now occupied by strata newer than the Coal-measures.

On examining the relation of the older to the newer formation it is found that, though in some cases the inclination of the older rocks is the same as that of the Coal-measures, the older rocks have been greatly denuded and worn into hollows before the coal-bearing strata were deposited.

The exact underground configuration is indeterminable, but it is observed that the strike of these older ridges trends roughly a little west of north. Along their margins underground explorations show that the coals deteriorate both

in thickness and quality, and often become a worthless mixture of shale and coal. This deterioration is not, however, due to the character of the older rocks, but to their

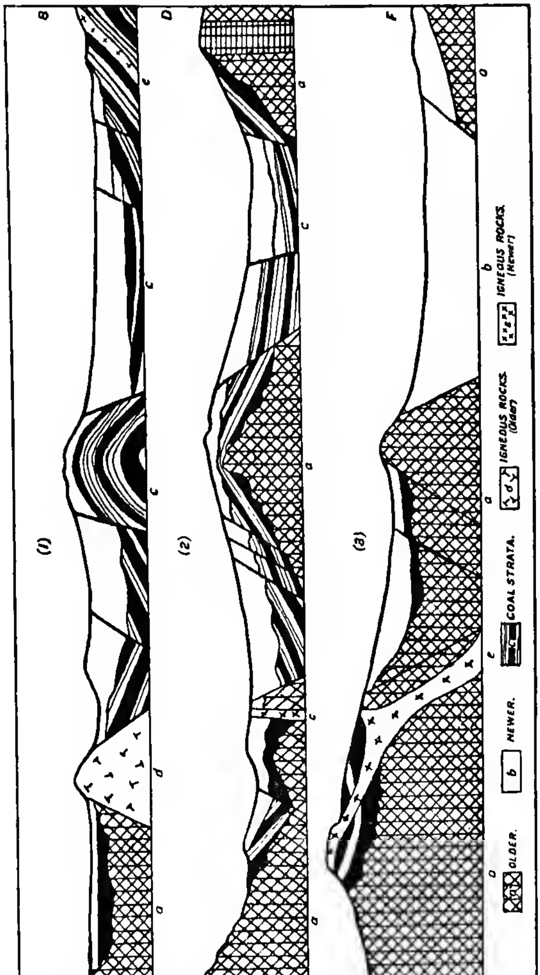


Fig. 12.—Section across Map (Fig. 11). Vertical Scale about 1½ Times.

forming the margins of the basin in which the Coal-measures were deposited.

An examination of the older rock masses in the visible

coalfields shows them to occur as irregular bosses, greatly denuded and worn into hollows before the deposition of the coal-bearing strata, but with a general trend a little west of north.

Cover.—From a consideration of the floor on which the coal-bearing strata were deposited we now pass to a study of the formations which cover them and conceal them from view.

The red rocks forming the first cover of the Coal-measure bear some resemblance to the Keele beds, the highest strata of the Coal-measures, with which, in fact, they were formerly grouped, but in North Staffordshire they were seen to rest unconformably on the Keele series and on the Carboniferous generally (p. 86).

This unconformity is still more marked in the southern coalfields of the Midland Province, where the Triassic rocks are found resting on the folded and eroded edges of the Cambrian strata and Silurian formation or on different members of the Carboniferous series. Not infrequently they rest directly on a seam of coal, an occurrence demanding some attention, for if it is intended to work this seam of coal beneath the red rock covering, a great quantity of water will be expected unless shut off from the seam by a layer of impermeable marl or shale belonging to the newer formation. In a colliery in Nottinghamshire, for instance, the valuable Top Hard Coal is not worked where it is close to the water-bearing Bunter Pebble Beds.

The cover of newer strata falls into two divisions—a lower sandstone and conglomerate series attaining a maximum thickness of 1,200 feet, and an upper sandstone and marl series over 1,000 feet thick. These thicknesses are, however, liable to sudden and unexpected variation. The lower sandstone and conglomerate series can be roughly subdivided into an inferior group of red sandstones, a middle conglomerate subdivision, and an upper red sandstone series. In the upper sandstone and marl series the sandstones occur below and pass upwards into the marls.

The upper division as a whole overlaps the conglomerates and sandstones of the lower division, and in many places along the southern margin of the basin the marls of the upper division bury up by overlap the sandstones at the base. We have here an instance of the infilling of a basin during gradual depression, as in the case of the Upper Coal-measures, but with a totally different class of rocks.

The juxtaposition of the upper marls with the sandstones and conglomerates of the lower division does not necessarily imply the existence of a fault; neither does the junction of the marls with the Coal-measures or the older rocks, since the newer rocks may, as before mentioned (p. 86), have been banked against cliffs or deposited in hollows of the older rocks.

The red covering strata, it is observed, are crossed by a number of curving faults trending nearly north or a little east or west of north—that is, roughly parallel to the trend of the older ridges.

The basin between the eastern and western coalfields is crossed by a gentle anticline, faintly but still discernible in the red rocks, and having a general north and south direction.

In the type region it was seen that the red rocks, newer than the Carboniferous, were similarly thrown into gentle folds, superimposed upon folds of greater intensity in the Coal-measures beneath. Both sets of folds, however, have the same general direction.

A trough fold (syncline) or a ridge fold (anticline) in newer rocks may be based vertically on an older fold affecting the older strata beneath, no matter what amount of denudation the older strata have been subjected to prior to the deposition of the younger strata. Posthumous folding, as this is called, may show itself by a corresponding arch or trough in the newer rocks, or by a thinning of the newer strata as they approach the axis of the fold. Sometimes, though rarely, a crest fold is superimposed on a trough fold, or *vice versa*, or the axes of the newer folds may not exactly coincide in position or direction with the older folding; but they nevertheless indicate the general direction of the folding in the older ridges. In taking the direction of folding in the newer strata as an indication of that expected in the older rocks, these differences must be kept in mind.

Folds, too, of small intensity and of open character often overlie folds of great complexity, of which the newer strata show no signs, especially in those cases where a long period of great earth movement and denudation has supervened between the older and the superimposed but gentler crust movement.

In a greatly folded region, for instance, the structure may consist, on the whole, of a number of broad anticlines

and synclines, but each broad anticline may be composed of smaller anticlines and synclines, the composite anticline forming what is called an anticlinorium; similarly, a broad syncline is frequently built up of lesser synclines and anticlines, the name synclinorium being applied to the composite synclinal fold. A simple anticline in the newer strata often overlies an anticlinorium, or a simple syncline overlies a synclinorium. A syncline in newer rocks may also overlie an anticlinorium in older strata, and *vice versa*. In all these cases folding in the newer strata, though it may outline that in the subjacent older rocks, does not necessarily show any signs of the complexity in the latter. For instance, the almost horizontal secondary rocks of the Somersetshire Coalfield rest on the much disturbed Coal-measures and older formations, and in Northern France the

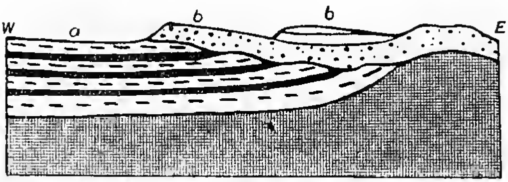


FIG. 13.—POSTHUMOUS FOLDING. FOLDS IN NEWER ROCKS (*b*); SUPERIMPOSED ON THE DENUDED FOLDS OF OLDER ROCKS (*a*).

secondary rocks, but little disturbed, overlie intensely folded and over-thrusted Carboniferous strata.

On the other hand, folding seen at the surface in newer rocks, and corresponding with folding in the rocks beneath, does sometimes occur as the result of one earth movement.

Applying the doctrine that folds in the newer strata roughly indicate the folds in the underlying older rocks to the area under discussion, the ridge fold traversing the centre of the basin is a posthumous fold of a simple character moulded on another and more ancient one of greater intensity, or is a recent fold in which the expected Coal-measures below and the newer rocks are equally involved. In the first case, the older rocks may have been greatly denuded before the newer strata were laid down on them, and may exhibit much complexity of structure; in the latter case, the structure of the newer rocks will approximate that of the older strata.

Experience gained in the type region and in the visible coalfields on the east and west of the basin leads us to

expect that the folding faintly discernible in the newer strata is of the posthumous type, and that the Coal-measures, if they exist at all beneath the red rocks, will be greatly denuded and will display a considerable complexity in structure.

A consideration of general principles, therefore, fixes the most suitable site for an experimental trial somewhere in the area between the two lines of structural faults H-H′ and K-K′ (Fig. 11, p. 90). A site directly on a line with the strike of the older rocks forming the ridge north of K′ will be avoided, nor will one be chosen towards the southern extremity of the fold, as experience in the exposed coalfields shows a marked deterioration in the quality of the seams to the south. We must not be disappointed to find that the coal-bearing strata have been greatly denuded,

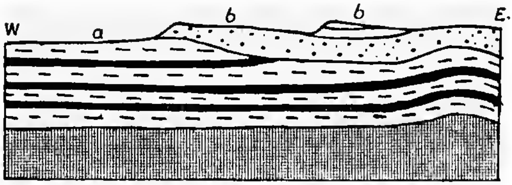


FIG. 14.—FOLDING IN NEWER ROCKS (*b*) CONTEMPORANEOUS WITH FOLDED OLDER ROCKS (*a*).

or even completely removed, before the deposition of the newer rocks.

Exploration Work.—Suppose a site is chosen at A towards the middle of the central ridge, and that the initial size of the hole is fixed according to the character of the strata it is expected to bore through and the depth to which it is intended to bore.

The boring starts in the lower red sandstones of the covering strata, which are found to be 300 feet in thickness. Grey measures are then entered, very similar in character to those of the productive series, but containing the fossil plant *Pecopteris arborescens*, unknown in the grey measures of the lower productive division, and characteristic of the Newcastle beds in the type region and in the neighbouring exposed coalfields. The district, however, being little known, too much reliance is not placed on this scanty palæontological evidence.

Beneath these grey measures red marls are met with containing the characteristic bands of green grits (Espley

Rocks). There can now, therefore, be little hesitation in concluding that the boring enters the Upper Coal-measures beneath the red rocks at the horizon of the Newcastle Group, and that the red marls and Espley Rocks represent the Etruria Marl Group of the type region. These are known to be conformable to the grey productive measures which are apparently entered at 800 feet from the surface.

A crystalline rock, evidently of igneous origin, is encountered after a few feet of grey productive measures have been penetrated. This rock agrees in the freshness of its minerals with the later intrusive igneous rocks met with in the exposed coalfields. Moreover, slight, though perceptible, alteration of the beds with which it is in contact are visible to the naked eye, and becomes still more obvious when the contact rocks are sliced and examined under the microscope.

The conclusion, therefore, is drawn that the boring tool has struck an igneous sheet or dyke either contemporaneous with the Coal-measures or intrusive into them, and not one of the igneous rocks associated with the strata of pre-Carboniferous age. The boring is then continued through the igneous rock, and again meets with Coal-measures and indications of coal-seams, until a coal 27 feet thick is met with at a depth of 900 feet below the base of the red cover, and 300 feet below sea-level, the surface of the ground being 600 feet above OD. The Coal-measure strata passed through consist in descending order of—Newcastle Beds (100 feet), Etruria Marls (400 feet), productive measures down to the top of the thick coal (100 feet). Besides the thick coal, a seam from 4 to 6 feet thick is met with a few feet below the red Etruria Marls, or at 200 feet below sea-level.

The direction of inclination of the strata was not satisfactorily determined.

At another site B, to the north of A, the Triassic cover is proved to be 400 feet in thickness, the Newcastle Group absent, and the Etruria Marls only 300 feet thick. The pre-Triassic denudation is, therefore, more excessive here than at bore-hole A. The thin coal noticed in the boring at A as lying 100 feet above the thick coal was recognized at 700 feet from the surface, or 100 feet below sea-level, again taking the surface elevation at 600 feet above OD. The strata evidently rise between A and B, or a fault with a downthrow between the two intervenes. Instead of the

thick coal, four or five coals from 4 to 7 feet thick are met with, so that the region of the thick coal has been passed, and the boring thus shows the same splitting up northwards of the thick coal as takes place in the exposed coalfield.

In a boring at C, to the west of B, the surface of the ground is 800 feet above OD. The red Triassic sandstones 500 feet thick, and the Etruria Marls down to the first seam of coal prove to be the same thickness as at B, and lying almost horizontally. The first coal then lies at sea-level, and, unless there is faulting, a fall of 100 feet must take place between C and B.

We will now suppose an attempt is made to prove whether the thick coal extends as far west of A as the point D.

Beneath the Trias a few feet of Etruria Marls are met with, and below these the first thin seam of coal in the grey productive measures; then almost immediately pale grey shales, not unlike Coal-measures, are entered, but found to contain beds of limestones, with Silurian fossils, interstratified with the shales.

The site D, therefore, indicates the position of the underground continuation of the ridge of older rocks. Supposing boring explorations had commenced at D instead of at A, a check to future explorations in the district would doubtless have ensued, unless the knowledge obtainable in the visible coalfield on the east, where valuable seams are seen to lie within a few hundred yards of the older ridges, had been taken into account.

Several explorations in the Midlands have met with the fate of bore-hole D, and adverse conclusions in many cases drawn as to the value of considerable areas from the results obtained in a single unsuccessful boring.

The geologist is not always sure of choosing a successful site, but he can in many instances determine beforehand the difficulties to be faced, and also indicate the areas in which exploration would be fruitless.

Suppose, for instance, it is resolved to prove the ground to the east of the fault K-K′. A site is selected some distance to the east of the fault, for not only may the coals be broken up near the fault, but the boundary faults are observed to correspond, both at the surface and in the boring at D, with the position of the older ridges. A site is therefore selected at E.

The amount of the throw of the fault K-K′ is unknown,

but the measures are known to dip eastwards, and at E a considerable thickness of the upper barren Coal-measures will probably occur above the productive strata.

The Triassic cover is known to be about 600 feet thick, and, as the boring is situated towards the centre of the syncline between the anticlinal region and the exposed eastern coalfield, the amount of pre-Triassic denudation will not be so great as over the anticline. A considerable thickness of the upper barren measures may therefore be expected. In addition to the Trias covering, it would be advisable to allow for at least 600 feet of Keele strata, 300 feet of Newcastle beds, 400 feet of Etruria Marls, and about 100 feet more of the grey measures above the thick coal-seam. Estimates must, therefore, be formed for a bore-hole of over 2,000 feet in depth, and, in choosing the initial size of the hole, due allowance must be made for inserting casing at several levels in passing through the great thickness of bad drilling ground that will certainly occur in the Keele and Etruria Marl groups. The first 600 to 800 feet of Trias being chiefly sandstone, will afford good drilling ground, and so need little casing, and this is taken into account when fixing the original size of the hole; but in a modern boring the size of the hole to begin with would not be less than 18 inches in diameter.

Red marls and sandstones with indeterminable plant remains and beds of conglomerate are met with beneath the Trias, and below these come more red marls containing a thin band of black limestone with *Spirorbis*. The sequence evidently agrees with the upper part of the Keele Group (Fig. 29, p. 156), and, unless there is faulting, some 600 feet of these rocks can be expected. Another band of limestone with *Spirorbis* is entered lower down, and the marls here contain several specimens of *Pecopteris arborescens*. At 670 feet below the base of the Trias grey measures are entered, with a band of blue limestone containing *Spirorbis* in abundance, and evidently the band at the summit of the Newcastle Group. Assuming the complete absence of faults cutting out some of the measures the position reached is about 700 feet above the grey productive strata, and there lies below about 300 feet of good drilling ground, formed by the sandstones of the Newcastle Group.

Below the Newcastle Group drilling is confidently carried on until a considerable thickness of the Etruria Marls has been penterated. On passing from the red ground of the

Etruria Marls into grey strata, extra care is taken to look for indications of the first thin coal-seam of the productive measures, and after that for the thick seam of coal. After striking the first thin coal, drilling operations will be conducted only by day.

In South Staffordshire and Warwickshire the pre-Carboniferous floor consists of broad, deep hollows and narrow ridges. Post-Carboniferous erosion has removed a great thickness of the coal-bearing strata off the ridges, but has left the Coal-measures in various stages of denudation in the intervening hollows.

The pre-Carboniferous floor of the Leicestershire Coalfield presents a broad platform of Archæan rocks, with here and there rocky prominences and shallow depressions, with some deeper hollows. Denudation at the close of the Carboniferous period has unequally affected the Coal-measures and Lower Carboniferous strata deposited on this platform. In some cases denudation has removed all the Carboniferous rocks that were laid down; in others it has stripped off the Upper Carboniferous rocks, while in other places it has left them more or less intact.

Since the red rock cover in Leicestershire is generally at its thinnest and never at its maximum, the thickness of covering strata is seldom great enough to make the Coal-measures lie at an unprofitable depth beneath them. Many explorations have been made to prove the extent of the productive strata under the red rocks, and are likely to be carried on still farther. It is evident that no very clear forecast can be made as to whether Upper or Lower Carboniferous strata will be encountered, or if both divisions will be absent; but the two divisions of the Carboniferous system in the Midlands are, as a whole, so distinct (p. 108) that there should be no doubt as to whether a boring reaches an horizon high up or low down in the Carboniferous sequence.

As an illustration, a colliery finds the Leicestershire coals of good quality and at shallow depths. It is therefore thought feasible that they exist to the west under an area not far distant from the workings.

A boring put down to test the ground starts in the red rocks of the Trias, and beneath these enters some red shales and sandstones containing marine shells, but otherwise similar to the Etruria Marl Group. The marine shells show that the Carboniferous strata do not belong to the upper barren series, but whether they are part of the Lower

Carboniferous, or are marine beds stained red, but belonging to the productive measures, is not certain, so the boring is carried down a few feet lower. When this is done, strata containing Carboniferous Limestone fossils in abundance are encountered, and it is evident that the productive measures were either never deposited or have been completely denuded away.

Attempts to reach coal-seams in the neighbourhood of the Leicestershire Coalfield have been made along the valley of the Soar, where the proximity of a direct railway route to London naturally encourages explorations. In some of these borings igneous and sedimentary rocks older than

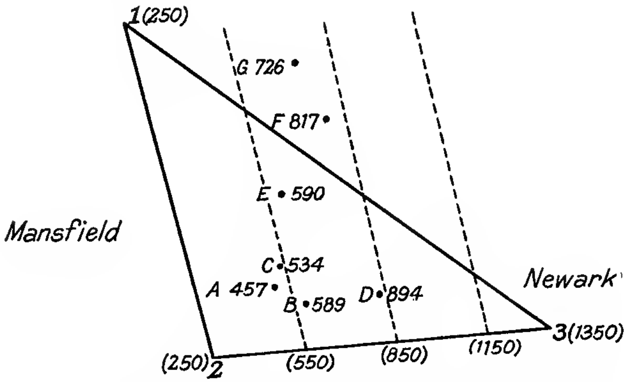


FIG. 15.—DIAGRAM ILLUSTRATING METHOD OF ESTIMATING DEPTHS TO COAL-MEASURES.

Figures give depths to Coal-measures in feet.

the Carboniferous, in others Lower Carboniferous strata, have been met with.

Examples have now been given as to the means by which the measures of a concealed coalfield in an anticlinal and synclinal region can be recognized. The Coal-measure sequence in its upper portion is of a clearly defined type, and the productive strata of no great thickness. The chief risk lies in the uncertainty of the position of the buried ridges of older rocks and the extent to which the productive measures have been denuded.

The application of local geological information in the elucidation of results obtained in pioneer explorations in partly unproved ground is illustrated (Fig. 15) by an area lying east and north-east of Mansfield on the eastern side of

the Pennine Hills. Here the risk of meeting older rocks does not exist; but travelling eastwards from the exposed coal-field a steadily increasing thickness of cover is encountered.

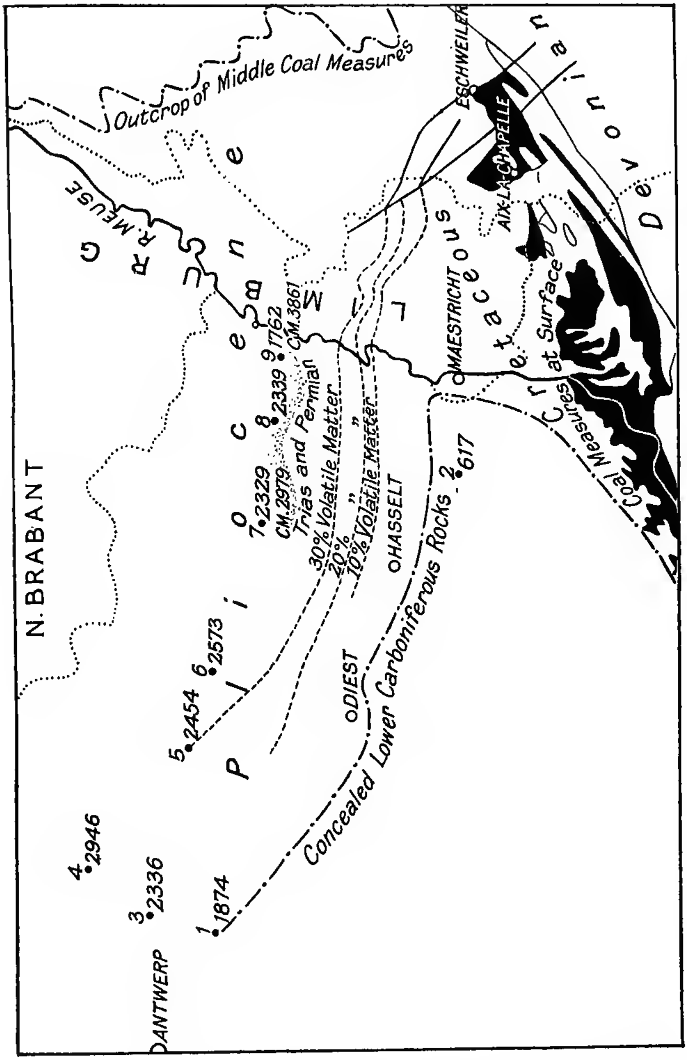


FIG. 16.—CONCEALED COALFIELD OF THE CAMPINE AND DUTCH LIMBURG.
1, Depth in feet to Lower Carboniferous Rocks; 2, to Devonian; 3-6, to Coal-measures; 7-9, to Red Rocks.
Scale, one inch = 16 miles

Moreover, the grey productive measures and Upper Coal-measures proved in the coalfield exceeds 5,000 feet in thickness. The Top Hard Coal, one of the most valuable

seams, and therefore the one chiefly sought for, was proved in a boring to the south to lie beneath 1,000 feet of barren Coal-measures. It is also previously known that over large areas east of the Pennines the Top Hard Coal and the measures above it were denuded before the cover of newer rocks was laid over them. The contemplated borings may therefore enter Coal-measures so high above the Top Hard that sinking to it is unprofitable, or they may enter Coal-measures below the horizon of this seam. In the Mansfield district a thick bed of blue shale resting on a dark earthy limestone from 1 to 2 feet thick lies 650 feet above the Top Hard Coal, and contains a rich and highly specialized fauna. Many of the fossils do not occur in any of the beds above or below this horizon, though a few ascend from below and are found again higher in the sequence. This easily recognizable bed, known as the Mansfield Marine Bed, was found in each of the trial borings at B, C, E, G. It was not found at F, and for some time it was uncertain if the boring had entered the Coal-measures above or below the horizon of the Top Hard Coal.

The same district affords an illustration of a method of obtaining a close approximate depth to the Coal-measures in a concealed area. In contrast to the buried coalfields situated to the west of the Pennine axis, the covering formations on the east side were laid down on an even surface sloping eastwards at a uniform rate, and not deformed by subsequent folding and faulting. Given the depth to the Coal-measure surface at the points 1, 2, 3, a triangle is constructed, and two of its sides divided into equal parts. A contoured outline of the palæozoic platform thus obtained is seen to fix approximately the depths to the Coal-measures as proved in the borings A-F.

The value of the Mansfield Marine Bed in fixing a definite horizon in the Coal-measure sequence of Yorkshire and Nottinghamshire is recognized. The want of such a distinctive horizon is illustrated in the explorations of the Kent Coalfield. Here the probable structure of the buried coalfield is based on the assumption that the east and west Mendip folding is continued beneath the Secondary formations, and thence undersea in the direction of Kent, to reappear at the surface in the exposed coalfields of Northern France. But although over 3,000 feet of Coal-measures containing several seams of coal have been proved in numerous borings, it is still uncertain to what part of the

sequence the Coal-measures belong, neither has it been found possible to correlate the coals in the several borings. Broad lithological and palæontological subdivisions of the Coal-measures have been suggested, but no distinctive fossiliferous horizon has been found. In Holland and Belgium (Fig. 16) an extensive tract of concealed Coal-measures has been revealed by boring, and elaborate and full detailed reports have been officially published.

CHAPTER IX

THE COALFIELDS OF SOUTH WALES AND THE FOREST OF DEAN.

General Introduction.

The coalfields of Great Britain arrange themselves in three separated areas, termed the Southern, Midland, and Northern Provinces. Each possesses distinctive structural, lithological, and palæontological features. In each a subdivision of the Carboniferous formation into (*a*) a lower marine phase represented by massive limestones in the Southern and Midland Provinces, and by intercalation of limestone bands with shales and sandstones in the Northern Province; (*b*) an upper subdivision, consisting chiefly of sandstones and shales containing an estuarine and possibly a fresh-water fauna, but with an occasional specialized marine fauna on not more than two or three horizons.

The Southern Province includes the coal-basins of South Wales, Forest of Dean, the coalfields of Somersetshire and Gloucestershire, and the recently discovered and concealed coalfield of East Kent. East and west folds predominate. The chief lithological characteristic is the development of a thick, massive sandstone (Pennant Sandstone) in the midst of the Coal-measures. South Wales and Somersetshire are noted for the occurrence of the highest plant-bearing Coal-measures containing several workable seams of coal. In addition to yielding house and gas coals, one part of the province, that of South Wales, contains the highest class of steam coal and the purest beds of anthracites known.

The Midland Province contains the coalfields of Central England. A north and south fold, well known under the name of the Pennine Anticline, is the dominant structural feature; while a great development of red but barren Coal-measures, overlying the chief coal-bearing strata, forms the main lithological characteristic. The fossil invertebrata occur in more or less defined zones in the Coal-measures.

The Midland Province furnishes best house, gas, and in Derbyshire, Nottinghamshire, and Yorkshire, some best steam coal.

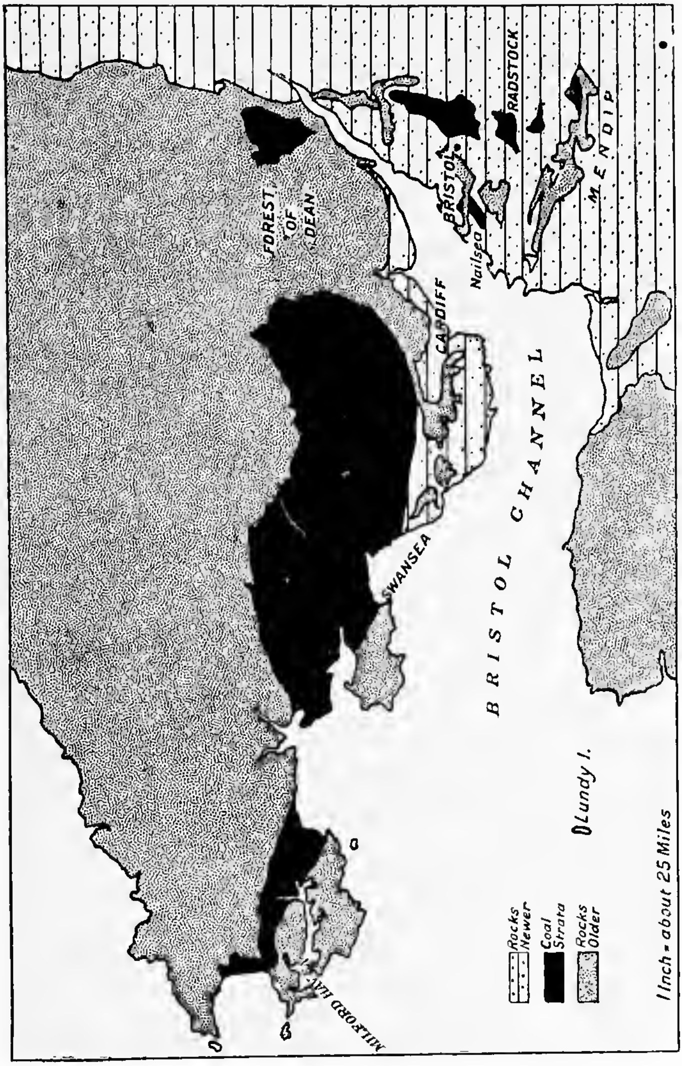


FIG. 17.—GEOLOGICAL MAP OF THE SOUTH WALES, FOREST OF DEAN, AND SOMERSETSHIRE COALFIELDS.

In the Northern Province, which includes the coalfields of Cumberland, Durham, Northumberland, and Scotland, sills and dykes of igneous material are of general occurrence.

Numerous workable seams of coal, not found in the Midland and Southern Province, make their appearance in the Lower Carboniferous rocks, and become an important source of supply in Scotland. The Pennine anticlinal plays the same part as in the Midland Province, separating the coalfields of Durham and Northumberland from those of Cumberland. A dominant north-east to south-west structure in the older formations that enclose the Central Valley determines the location of the Scotch coal areas. Locally, the Lower Carboniferous rocks are zonable.

The Northern Province is an area of gas and coking coals. It also furnishes house and steam coals.

In all three Provinces the best and most important seams lie in the lowest part or towards the middle part of the Coal-measure sequence.

Southern Province.

The east and west folds visible in the exposed coalfields of South Wales and Somersetshire, and now proved to exist in the concealed coalfield of East Kent, belong to a system prevalent in the coalfields of Northern France and Belgium. The folds are the result of a powerful thrust acting from the south, which buckled the Carboniferous and older strata into a number of crest and basin folds having their longer axes directed latitudinally.

Formations older than the Carboniferous are involved in the folding, and these occur in the centres of the crest ridges, and in very disturbed areas the older formations have been thrust over Carboniferous strata. The areas occupied by these older rocks, and the number, continuity, and shape of the folds, remain unknown, as they are concealed beneath the Secondary formations to the east of the Somersetshire Carboniferous area. The folding (frequently termed 'Armorican') was mainly completed before the deposition of the Trias, but movement having the same direction took place in early Mesozoic times. Along the south coast of England a still later disturbance on the same general line came into operation, and there is some reason to believe that some of the west-south-west folds in South Wales belong to this later period.

The general succession of the Carboniferous strata in the Southern Province is shown on p. 111.

One of the characteristic features of the Coal-measure

sequence in each district is the thick mass, seldom less than 1,000 feet thick, of the practically barren sandstones and shales of the Pennant Series, thus separating a lower productive from an upper productive series in South Wales and Somersetshire. In the Kent Coalfield it is still undecided if Upper Coal-measures are present, and whether any Lower Coal-measures were deposited; or, indeed, except structurally, whether the Kent Coalfield is rightly included in the Southern Province or belongs to an area by itself.

		South Wales.	*Somerset.*	*Kent.*
Coal-measures.	Upper	Supra-Pennant Series.	Radstock Series. Farrington Series.	— Coal-measures.
	Middle	Pennant Sandstone Series.	Pennant Series.	Coal-measures.
	Lower ?	Steam Coal Series.	New Rock Series. Vobster Series.	? Absent. ? Absent.
		Millstone Grit Series.	Millstone Grit Series.	Absent.
		Carboniferous Limestone Series.	Carboniferous Limestone.	Carboniferous Limestone.

The Coalfield of South Wales.

The coalfield extends westwards from near the estuary of the Severn between Cardiff and Newport to St. Bride's Bay, a distance of 90 miles. Its greatest width, 20 miles, is in Glamorganshire; an average width of about 15 miles is maintained to Swansea Bay. Westward the coalfield contracts, and in West Pembrokeshire it has narrowed down into a strip scarcely 3 miles across. It lies open to the sea on the south and west. To the north there rise the desolate Old Red Sandstone Hills of the Black Mountains and the Fans of Brecon.

Including the parts covered by the sea in Swansea Bay and Carmarthen Bay, the area of the coalfield amounts to 1,000 square miles, with a reserve of high-class coal estimated at over 26,000,000,000 tons, of which 6,310,292,214 tons are anthracite and 3,936,657,410 tons first-class steam coal. The coalfield exists to-day as an east and west basin fold sunk in the Old Red Sandstone formation and Lower Carboniferous strata which bound it on all sides except on the south, where the margin of the

coalfield is breached by the sea in Swansea Bay and Carmarthen Bay.

Deep longitudinal valleys have been, and to a great extent are still, the main factor in determining the location of colliery shafts and the mining towns. Levels are opened up along the steep-sided valleys, and the mines are unwatered by natural drainage. Shafts, at first sunk to the Steam Coal Series near their outcrops, have gradually crept down the valleys, in which denudation, by removing the overlying strata, has brought the coals within workable reach. But geological structure also plays an important part in the location of the coal-workings. Viewed broadly, the chief structures are three in number:

1. An east and west folding involving the coalfield as a whole, and determining the main basin fold; but the basin is broken in places by subsidiary east and west anticlines that bring the lower coals within mineable reach. These anticlinal folds are sometimes expressed by faulting, as instanced by the Moel Gilau Fault (p. 121). West of Swansea Bay the general east and west disturbances that border the main synclinal fold on the south become very distinct, and, increasing in intensity westward, introduce the greatly complicated structure along the southern margin of the Pembrokeshire Coalfield.

2. The main basin is crossed by a pronounced and regular system of faulting having a direction from north-north-west to south-south-east. West of the Rhondda valleys these faults have a large aggregate downthrow west, which gradually introduces higher and higher measures until in the Swansea district the lower coals are depressed beyond the mining limit of 4,000 feet. The disturbances mentioned have taken little or no part in defining the present physical features of the coalfield, but are generally completely ignored by the main valleys.

3. A third and powerful system of faulting and folding trending west-south-west commences at the Vale of Neath, and thence westwards is found in equal intensity in the Cribarth, Careg Cennen, and Tawe valleys—disturbances along which the rivers continue their course to the sea.

The age of the faulting remains an open question. The north-north-westerly faults are certainly in places post-Liassic, but their throw is generally greater in the Carboniferous than in the Secondary formations. Since the west-south-west disturbances have a marked effect on the river

system, there are some grounds for believing that some of them belong to a late geological period. On the other hand, in Pembrokeshire these disturbances are plainly moulded on one that intervened between the Ordovician and Silurian periods, and was renewed and became extremely active after the Carboniferous period.

The Carboniferous sequence in South Wales is divisible into the following groups of strata:

		Thickness in Feet.
Coal-measures	Supra-Pennant Series, base the Mynyddislwyn Coal or its correlatives	400 (N.E.) to 1,000 (S.W.)
	Pennant Series, base the Rhondda No. 2 Coal or its representatives	700 (N.E.) to 3,000 (S.W.)
	Steam Coal Series: (1) Upper or Red Ash Series, (2) Lower or White Ash Series	1,000 (N.E.) to 4,000 (S.W.)
	Farewell Rock Shales and sandstones Basal grits and conglomerates	300 to 1,500
	Carboniferous Limestone Series.	

Important bodies of hæmatitic iron-ore occur in the Carboniferous Limestone between Cardiff and Bridgend. Coal-seams are absent, but the limestone contains beds of dolomite and also furnishes a good and abundant supply of flux. Coals appear towards the summit of the Millstone Grits of sufficient thickness and quality to have attracted attention in a few places. High-class refractory materials are found in the quartzitic sandstones of the Millstone Grits, those of Dinas having a world-wide reputation.

The Coal-measures naturally fall into an Upper Coal Series, a Middle Pennant Sandstone Series, and a Lower or Steam Coal Series. This threefold grouping is based on differences in lithological characters, and does not correspond to the tripartite subdivision of the Coal-measures as determined on palæontological evidence founded on the vertical distribution of the fossil plants. On palæobotanical grounds it is considered that the Lower Coal-measures are not represented in South Wales, and that the succession commences with the Middle Coal-measures (lower part of the Steam Coal Series), and passes up through a transition series (upper part of the Steam Coal Series) into Upper Coal-measures.

Considerable variations of lithological characters and marked changes in the coal-seams are noticeable in the Coal-measure sequence as it is followed from east to west.

The three lithological subdivisions and the numerous seams can be identified with much accuracy up to the Vale of Neath. This deep and distinct trench, trending north-east and south-west, separates the coalfield into an eastern and western portion. Groups of strata and individual coals are readily identifiable through Monmouthshire, parts of Brecknockshire, and eastern Glamorganshire up to the Vale of Neath. West of this valley the rock groups begin to lose their individuality, and at the same time the seams of coal change. Proceeding westwards, the identification of lithological rock types and coals becomes increasingly difficult, until in West Pembrokeshire a correlation with the sequence in Monmouthshire completely breaks down. It is therefore useful to take advantage of the physical break afforded by the Vale of Neath, and to consider the Coal-measure sequence in its development in the east separately from its sequence in the west. Of the links connecting east with west, the Millstone Grits, though with varying characters, form the base of the Steam Coal Series. There is not much doubt that the Black or Rock Vein of East Monmouthshire is on a level with the Nine Feet of East Glamorganshire and with the Stanllyd of West Glamorganshire, and that the Timber Vein is its equivalent in East Pembrokeshire. This seam lies towards the middle group of coals belonging to the Lower or White Ash Series. At the base of the Pennant Series in Monmouthshire there lies a coal called the 'Tillery Vein,' which, traced westwards, is known successively as the Brithdir and Rhondda No. 2 Seam. Crossing the Neath Valley the Ynysarwed Coal is taken as the equivalent seam, and is recognized under this name as far west as the Amman Valley; west of this it is known as the Brondini Vein in the Gwendraeth Valley, west of Llanelly. This nomenclature applies to the north crop only; a different set of names given subsequently (p. 116) is in use for the south crop.

The chief change in the associated measures is the gradual incoming westwards of the Pennant-like sandstone in the upper part of the Steam Coal Series.

The Middle or Pennant Series maintains its individuality up to the Avan Valley, when seams of coal make their appearance, and are, or have been, worked to some extent east of the Vale of Neath. West of this valley these and other seams become of importance, and it is feasible to subdivide the Pennant Series into two parts—Upper and

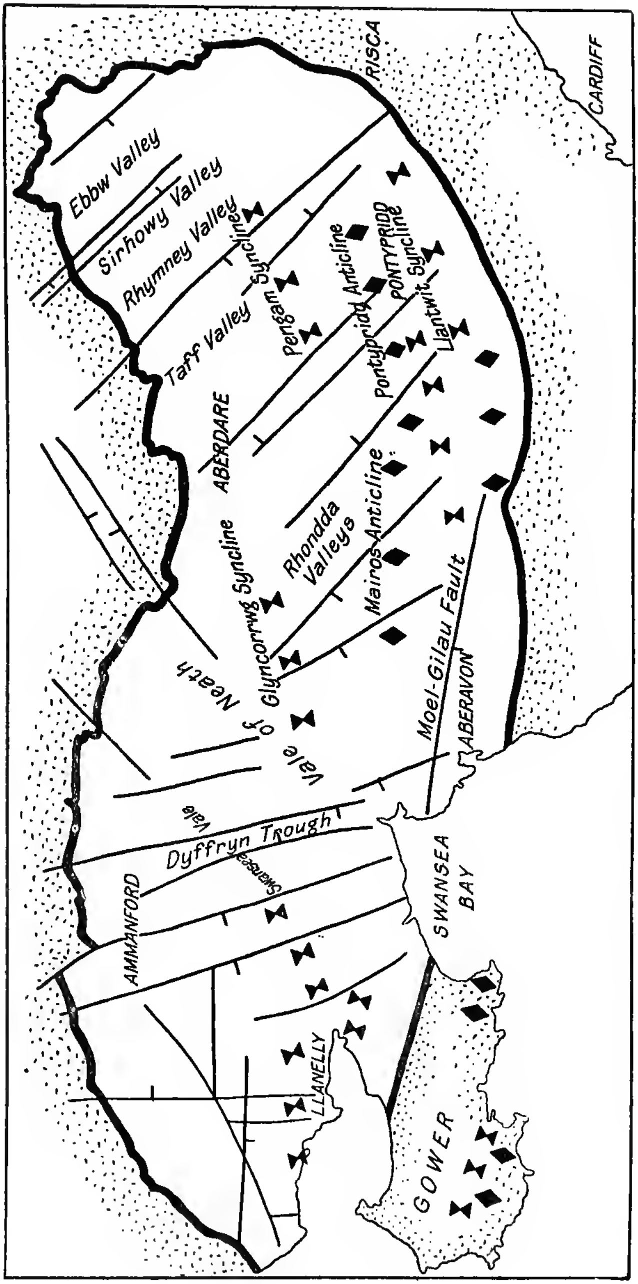


FIG. 18.—SKETCH MAP OF THE EASTERN PART OF THE SOUTH WALES COALFIELD.
Scale, one inch=8 miles.

Lower Pennant—on the horizon of a coal called the 'Hughes Vein,' which corresponds to the Wenallt Coal of the Avan Valley. Much confusion, indeed, has arisen from the adoption of this terminology by some, and by others applying the term 'Lower Pennant' to the Pennant-like sandstones in the upper part of the Steam Coal Series and using the term 'Upper Pennant' for the entire sequence above the Hughes Vein, including the Upper Pennant Series of the table on p. 113.

At the base of the Upper Pennant Series the Mynyddislwyn Vein of Monmouthshire is traceable with more or less certainty into the Llantwit No. 3 Vein of the Rhondda Valley and the Wernffraith of the Swansea district.

East of the Vale of Neath.

East of the Vale of Neath the Steam Coal Series presents the following development:

Monmouth.	*East Glamorgan.*	*South Crop.*
Tillery (Brithdir).	Rhondda No. 2 (Brithdir).	Rock-Fawr.
Measures.	Measures with Rhondda No. 3, Abergorky, Gorwllyn coals.	Measures with Tormynydd, Albert, and Victoria coals.
Elled.	Two Feet Nine, Four Feet.	Rock Vein.
Measures with Big and Three-Quarters coals.	Measures with Six Feet.	Measures with the Bodwr Fawrs, Six Feet, and Nine Feet coals.
Black, Ras Las, Rock, or Bydyllog Coal.	Nine Feet.	Nine Feet.
Measures.	Measures.	Measures.
Old Coal.	Lower Four Feet, Gellideg.	Cribbwr Fawr.
Measures.	Measures.	Measures.
Garw.	Garw or Cnapiog.	Cribbwr Fach.
Measures.	Measures.	Measures.

Farewell Rock of the Millstone Grit Series.

The strata consist of *dark* shales, fireclays, and clays, with some sandstones in the lower part and *grey* shales, sandstones, and clays in the upper part. Along the northern crop, between Blaenavon on the east and Hirwain on the west, the seams rise gently to the north, and have been mined extensively in open workings ('patchworks'), together with the associated ironstones. This practice has almost ceased, and the coals of the Steam Coal Series are obtained

now by pits sunk on the deep in the valleys excavated through the Pennant Series, and also by shafts commencing in the Pennant Series, where this has not been removed by denudation. On the west and along the south crop the

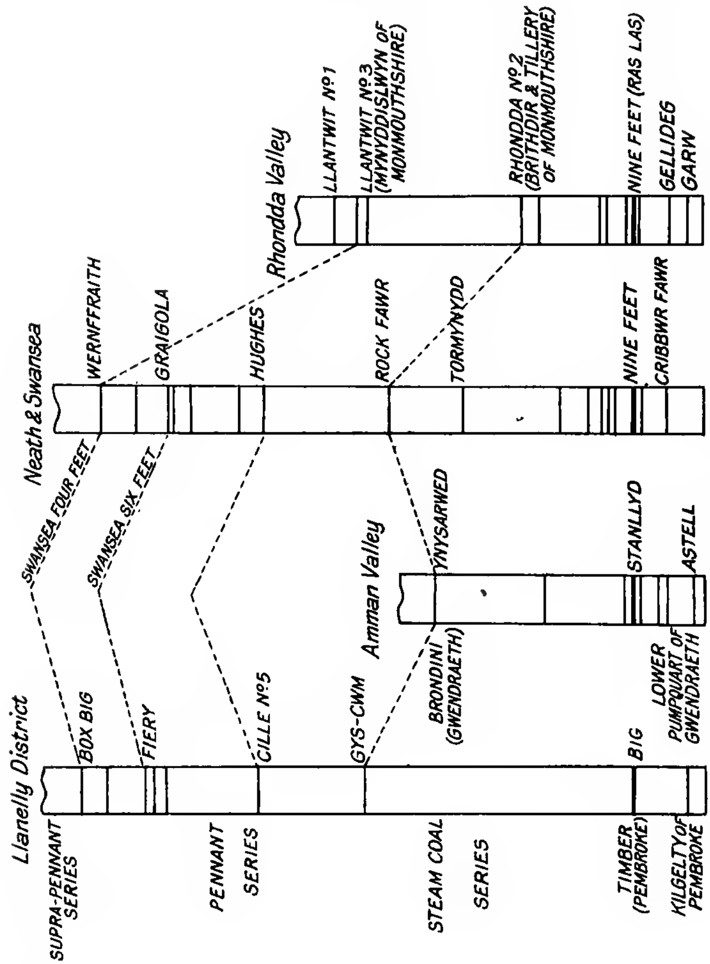


FIG. 19.—VERTICAL SECTIONS OF THE SOUTH WALES COALFIELD.
Scale, one inch = 2,000 feet.

coals are highly inclined, and not infrequently approach verticality. The measures expand rapidly from east to west, and also from north to south, but locally, near Pontypool, there is a southerly and westerly attenuation. Lenticular beds of sandstones and grit appear above the horizon

of the Elled Coal in Monmouthshire. These gradually expand westwards, to become the thick masses of Pennant-like sandstone and quartzitic sandstones known as 'cock-shot' when developed in the lower part of the sequence above the Two Feet Nine Seam, and as 'Llynvi' or 'Tor-mynydd' Rock in measures a short distance below No. 3 Rhondda, the next seam below No. 2 Rhondda.

In Monmouthshire the Pennant is mostly grey sandstone with subordinate beds of grey shale and grey sandy shales which increase in thickness and number going westwards. Important seams in the Aberdare (Cynon) Valley in descending order below No. 2 Rhondda are: No. 3 Rhondda, Hafod, Abergorky, Graig, Gorwllyn (base of Red Ash Series), Two Feet Nine, Aberdare Four Feet, Aberdare Six Feet, Red Vein, Nine Feet or Ras Las, Bute Vein, Yard (Upper and Lower), Seven Feet, Five Feet, Gellideg. Well-known seams of the Rhondda Valley include: Rhondda No. 3, Hafod, Abergorky, Pentre, Gorwllyn, Two Feet Nine, Four Feet, Red Vein, Nine Feet, Five Feet, Gellideg. West of the Ogwr Valley the chief seams in the Steam Coal Series below Rhondda No. 2 occur in the following descending sequence: Upper and Lower Bridge, Lantern Vein, Bodwr Fach, Bodwr Fawr, Esgyrn, Smutty Vein, North and South Fawr, Second and Third South Fawr, Six Feet, Slatog Fawr, Slatog Fach, Nine Feet or South Vein, Fiery or Danllyd, Five Quarters or Pumpquart, Cribbwr Fawr, Cribbwr Fach.

The Pennant Sandstone Series occupies the high ground in the central and southern parts of the coalfield. It forms an elevated plateau deeply dissected into a series of sub-parallel valleys tending roughly north and south. It participates, though in a more marked degree, in the westerly expansion observable in the Steam Coal Series, and at the same time seams of coal make their appearance and become of workable thickness in the Glyncorwg district, south-west of Aberdare. In the Pontypool district the Mynyddislwyn and Tillery Vein are 800 feet apart; Llantwit No. 3 and Rhondda No. 2 are separated by 1,700 feet of practically barren measures in the Llantwit and Rhondda valleys; and in the Avan Valley, west of Glyncorwg, where, however, the identification of the seam corresponding to Llantwit No. 3 is in dispute, the expansion on the lowest computation exceeds 1,800 feet, and not unlikely amounts to over 2,000 feet. In the Avan district the Wenallt Coal,

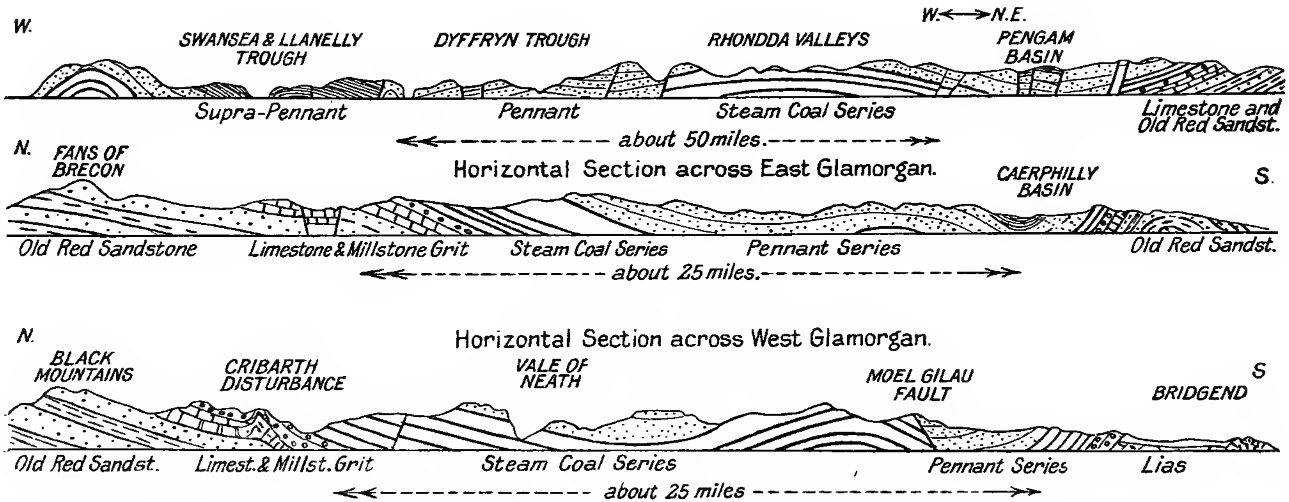


Fig. 20.—Sections across the South Wales Coalfield.
Vertical Scale, about 3 times the Horizontal.

1,300 feet above Rhondda No. 2, is somewhat extensively worked.

East of the Neath Valley the measures with the Mynyddislwyn or Llantwit No. 3 Coal at their base are confined to Monmouthshire and to the Llantwit basin.

A bed containing marine shells occurs above the Bydyllog Coal in Monmouthshire, but no attempt has been made to trace this band over the coalfield. The marine band associated with the Rosser Vein Ironstones belongs in reality to the Millstone Grit Series. *Carbonicola robusta* has been found only in connection with the Cnapiog (Garw) Coal. The roof of the Ras Las Seam contains an assemblage of *Naiadites carinata*, *N. modiolaris*, *N. quadrata*, *Anthracomya modiolaris*, and *A. williamsoni*. *Anthracomya adamsi* has been recorded from the measures above the Big Coal of the Rhymney Valley, and above the Black Pins and Soap Vein ironstones of Ebbw Valley. The zonal value of these fossils in South Wales awaits further investigation. *Anthracomya phillipsi* has never been recorded from the Steam Coal Series. It is rare in the Pennant Series, except on the horizon of Rhondda No. 1, the next seam above Rhondda No. 2. It is of more general occurrence in the supra-Pennant Series. The following fossil plants are abundant in the supra-Pennant Series: *Sphenopteris neuropteroides*, *Alethopteris serli*, *Sigillaria tessellata*. Associated with these are *Alethopteris lonchitica* and *Pecopteris miltoni*. The same plants occur in the Pennant and upper part of the Steam Coal Series, but with a greater preponderance of Middle Coal-measure species. In the lower part of the Steam Coal or White Ash Series *Sphenopteris neuropteroides* and *Alethopteris serli* are absent, and there is a mingling of some Lower Coal-measure plants with Middle Coal-measure forms.

East of the Vale of Neath the main basin fold is clearly delineated by the outcrop of the Millstone Grits and Steam Coal Series. The major syncline is broken by the subsidiary Pontypridd anticline, which introduces into the heart of the Pennant country a small inlier of the Steam Coal Series near Pontypridd and in the Ely and Ogwr valleys to the west. It is traceable eastwards in the Pennant Series, carrying on its north side the syncline of supra-Pennant Series of Blackwood and Pengam, and on its south side the supra-Pennant basin of Caerphilly. West of Pontypridd the Llantwit basin lies on the south side of the Pontypridd

anticline; farther to the west and north the Ton-y-efail syncline in the Pennant Series lies between the Pontypridd anticline on the north and the Mairos anticline north of Llanharaw. At Gilfach the Pontypridd anticline dies away, but farther north the parallel Maesteg anticline commences at Ogwr-fawr, and thence extends westwards across the Garw-Llynvi valleys, bringing up the Steam Coal Series along its course. The Maesteg anticline increases in intensity westwards, and as it does so the east and west Moel Gilau Fault makes its appearance, and gradually increases into a downthrow south of over 700 yards. It is noticeable that the combined effect of the Moel Gilau Fault and the Maesteg anticline is to introduce an outcrop of highly inclined Steam Coal Series at Cwmavon, with Pennant Sandstone on the north and south. Between the Maesteg anticline and the northern margin of the main syncline there intervenes the shallow but broad syncline of Glyncorwg, which includes the whole, or nearly the whole, of the Pennant Series, and beneath which the Steam Coal Series lie practically intact.

The east and west folds are crossed at somewhat regular intervals throughout the coalfield by many large faults trending generally north-north-west. Some of these extend up to and end in the Neath disturbance, but are not directly traceable across it. Their aggregate downthrow west is greater than their aggregate downthrow east. They also show a tendency to run in pairs, throwing down a trough between them, of which the Darenddu and Ty-mâwr trough faults of the Pontypridd district furnish a good illustration.

The part of Glamorganshire between the Taff and Neath rivers have supplied the bulk of the famous Welsh steam coals, those of the Aberdare and Rhondda valleys being of world-wide reputation. Proceeding eastwards into Monmouthshire these high-class steam coals of the Steam Coal Series become more bituminous, and in the Tillery Vein, and more particularly in the Mynyddislwyn Vein, Monmouthshire possesses a highly bituminous house coal. Along the south crop the coals of the Steam Coal Series are decidedly more bituminous than along the north crop. Monmouthshire produces steam, house, manufacturing, and some coking and gas coals. Analyses are given on p. 122.

The tables of analyses show that the coals of Monmouthshire and those of the south crop in East Glamorganshire

are more bituminous than the coals in the north crop of this area. The analyses of the Aberdare Six Feet and Nine Feet coals indicate an increasing anthracitization in passing westward; and in the case of the Aberdare Six Feet Coal a marked lowering in the ash contents.

MONMOUTHSHIRE.

	Carbon.	*Hydrogen.*	*Oxygen.*	*Nitrogen.*	*Volatile Matter.*	*Ash.*
Mynyddislwyn	86·94	5·64	5·84	1·58	37·52	7·3
Tillery ..	86·28	5·53	6·54	1·65	38·42	4·3
Three-Quarters	87·81	5·09	5·64	1·46	32·39	6·2
Black or Ras Las	88·24	5·24	4·92	1·60	34·41	5·3
Old Coal ..	87·93	5·30	5·50	1·27	31·48	5·0

EAST GLAMORGANSHIRE, SOUTH CROP.

	Carbon.	*Hydrogen.*	*Oxygen.*	*Nitrogen.*	*Volatile Matter.*	*Ash.*
Rock Fawr ..	85·15	5·05	8·13	1·67	38·07	3·25
Four Feet ..	85·20	5·40	9·40		30·60	2·60
Nine Feet (Morfa) ..	86·30	5·34	8·35		30·40	5·50

EAST GLAMORGANSHIRE, NORTH CROP.

	Carbon.	*Hydrogen.*	*Oxygen.*	*Nitrogen.*	*Volatile Matter.*	*Ash.*
No. 2 Rhondda	89·32	5·09	3·74	1·85	27·21	5·94
Aberdare Six Feet (Pontypridd) ..	91·65	4·45	2·14	1·78	15·69	3·41
Aberdare Six Feet (Glyncastle) ..	93·63	4·01	1·91	0·45	—	1·30
Nine Feet (Pontypridd) ..	91·43	4·61	2·44	1·52	19·39	5·70
Nine Feet (Resolven) ..	92·65	3·96	1·98	1·41	8·52	6·20

The carbon, hydrogen, oxygen, and nitrogen are given in percentages calculated for the coal after deduction for moisture, ash, and combustible matter; the percentage of volatile matter is calculated on the coal exclusive of moisture and ash. The ash is expressed in the percentage of coal dried at 103° C.

West of the Vale of Neath.

West of the Vale of Neath the chief seams of the Steam Coal Series occur between Swansea Bay on the east and Carmarthen Bay on the west for the south crop; and between Glyn Neath, and Kidwelly along the north crop. They occur in the following order:

North Crop.	*South Crop.*
Ynysarwed or Brondini	Penlan, Rock Fawr, or Wernddu Coal.
Measures with Red, Carway Fawr, Big, Stwrain, Eighteen Feet, Four Feet, or Cornish coals	Measures with Fawr seams, Fiery, Four Feet, Six Feet coals.
Stanllyd or Nine Feet	Big or Nine Feet.
Measures with Brass, Middle, and Lower veins, Gwendraeth, Lower Triquart, Lower Pumpquart coals	Measures with Five Quarters.
Measures	Measures.
Rhas Fach	Cribbwr Fawr (Old Coal).

Between the Ynysarwed and Nine Feet, in the east, about 1,900 feet of measures intervene, which increase to 2,300 feet, separating the Brondini and Stanllyd coals in the west. In the Gower Peninsula 3,000 feet of measures separate the Penlan and Big veins. But the greatest contrast with eastern Glamorganshire takes place in the Pennant Series, if the Wernffraith of Swansea, the Swansea Four Feet of Gower, and the Box Big of Llanelly be taken as the equivalent of Llantwit No. 3. Not only is there a westerly expansion from 1,600 to 3,000 feet, but several important seams of coal are developed in the upper half of the sequence—that is, above the Hughes Vein of Swansea, which corresponds to the Wenallt Coal of the Glyncorwg basin. These seams in the Swansea district are named in descending order: Swansea Five Feet, Swansea Six Feet or Graigola, Swansea Three Feet, Swansea Two Feet (corresponding to the Llanelly Four Feet), Fiery Vein, Golden Vein, and Bushey Vein. While, however, it is generally admitted that the Wernffraith, Swansea Four Feet, and Box Big are identical, some authorities regard the Graigola Seam, 800 feet below the Wernffraith, as the equivalent of the Llantwit No. 3 Seam. Divergent views also are held as to the identification in different districts of the seam corresponding with Rhondda No. 2. Though such differences affect the measurements assigned to the Pennant

Series, the fact remains that between the Nine Feet Seam and the highest measures known in Monmouthshire there lie 1,900 feet of strata, as compared with over 5,000 feet in Gower. Until some very definite bed of rock or fossil horizon has been located, the exact grouping of the great thickness of strata and the comparison of the groups of one district with another is likely to lead to much diversity of opinion. In a greatly disturbed region, such as that of West Glamorganshire and Carmarthenshire, the next-in-order principle is naturally attended with well-nigh insuperable difficulties, since the coals in the Pennant Series vary in character and relative position from place to place.

The Steam Coal Series along the northern crop have undergone much deformation, and are overfolded and overthrust, so that direct measurements of thicknesses are difficult to obtain. Instances of duplication and even triplication of a coal-seam occur, as at the Palleg Colliery, in which the Big Vein was found in three 'overleaves.' The coals along the north crop furnish a large amount of the anthracite obtained in South Wales. Around Ystradgynlais and in the Amman Valley the coals occur below the Ynysarwed in the order of Pantrhydydwr, Upper and Lower Pinchin, Welsh, Red, Soap, Stwrain, Upper Four Feet or White, Upper Black, Pencraig (Little or Four Feet), Harnlo, Big or Stanllyd, Lower Black, Brass, Trigloin, Brynlloi or Little, Little Brass, Middle Vein, Lower Vein, Bryn, and Astell. A new set of names is introduced in the Gwendraeth Valley below the Brondini or supposed Ynysarwed Vein: Carway Fawr (Red Vein of Amman), Big, Green, Ddugaled, Hweh, Stanllyd, Gras Uchaf, Gras Isaf, Brasslyd, Gwendraeth, Lower Triquart, Little Vein, Lower Pumpquart, Rhas Fach, and measures down to the Farewell Rock 40 feet. With the exception of the Stanllyd (5 to 9 feet thick) few of the seams exceed 3 feet in thickness, which is less than the average thickness of the seams in East Glamorganshire.

The Pennant Series, west of the Vale of Neath, is capable of a twofold subdivision into (1) a lower part containing massive sandstone, and (2) an upper part consisting of shale and sandstone in about equal proportions, with several workable seams of coal. The base of the upper part is taken at the bottom of the Hughes Vein. In the Swansea district the coals above the Hughes Vein are the Two Feet, Three Feet, Six Feet (Graigola), Five Feet, Four

Feet (Wernffraith)—corresponding to the Bushey, Golden, Fiery, Four Feet, and Box Big or Six Feet of the Llanelly district. These coals thin away and disappear northwards and north-westwards. Owing to this fact and to the great thickness of the Pennant Series, mining operations are at the present mainly confined to workings of the Pennant seams of the Swansea and Llanelly basins, and to the coals of the Steam Coal Series along the northern and southern crops. In the deepest parts of the basin a pit commencing at the horizon of the Wernffraith would not reach the chief coals of the Steam Coal Series under a depth of approximately 4,500 feet.

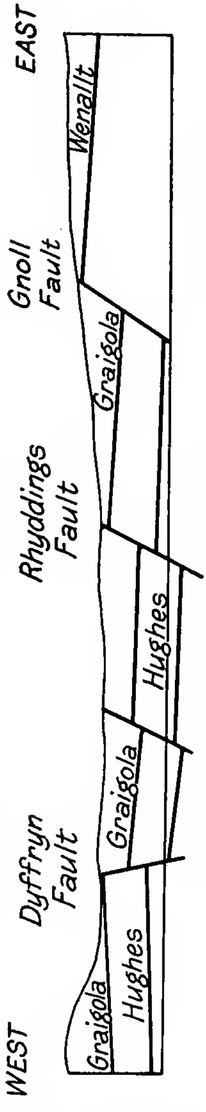


Fig. 21.—Section across the Neath Trough. Scale, one inch = 5,000 feet.

The Vale of Neath, as previously mentioned, marks the first belt of faulting with an east-north-east trend. To the west, this system of faulting becomes intensified, but the belts of disturbances are accompanied by much overthrusting. At the same time the northerly or north-north-westerly faults remain prominent structures, and, as in East Glamorganshire, tend to run in pairs and to occur at more or less regular intervals. Of trough faults belonging to this system, those of Rhyddings and Dyffryn are striking illustrations. The Rhyddings Fault, with a downthrow west and having a nearly north and south trend, commences near Baglan on the south side of the Vale of Neath. With a throw of 420 feet near the eastern lip of the valley, it has increased to 1,584 feet throw at Cadoxton after its union with the Gnoll Fault coming from the south. Farther north, at Bryncoch, the throw is about 1,600 feet. Still increasing northwards, the throw, where it crosses the Tawe Valley, is estimated at 2,400 feet. Diminishing

northwards, it nevertheless continues across the north crop into the limestone country with a throw of 400 feet at the outcrop of the Main Limestone. The total distance is nearly sixteen miles. The Dyffryn Fault, with a downthrow east of about 1,100 feet near Bryncoch, is subparallel to the Rhyddings Fault, but terminates to the north before reaching the outcrop of the Lower Carboniferous rocks.

	Carbon.	*Hydrogen.*	*Oxygen.*	*Nitrogen.*	*Volatile Matter.*	*Ash.*
Hughes Vein ..	92·64	4·58	1·67	1·11	18·65	3·60
Ynysarwed (Dulais) ..	93·02	4·19	2·79		9·97	2·64
Ynysarwed (Swansea Vale)	93·71	3·69	2·60		7·44	4·40
Red Vein (Ystradgynlais) ..	92·58	3·91	3·50		7·70	3·00
Red Vein (Ammanford) ..	93·22	3·85	2·92		8·78	2·80
Stanllyd (Ystradgynlais)	94·43	3·33	1·27	0·97	5·30	1·10
Stanllyd (Ammanford ..	94·06	3·47	1·26	1·21	5·71	3·60
Stanllyd (Kidwelly) ..	93·86	3·44	1·50	1·20	5·67	2·10
Cnapiog ..	93·93	3·65	2·42		6·30	2·40

A comparison of these analyses with those of the seams in Monmouthshire and of the south crop shows a marked increase in the carbon percentage, a diminution in volatile matter, and a marked decrease in the percentage of ash.

The restriction of anthracites to definite areas has lead to much discussion. Four explanations have been put forward: (1) That the anthracitized seams were originally bituminous coals which have been exposed to a high temperature under a great thickness of sediments; (2) that they were bituminous seams subsequently altered by the neighbourhood of plutonic rocks; (3) that they have been affected by slip-cleavage in the disturbed areas; (4) that the differences in composition between the bituminous and anthracitic coals are due to original composition (p. 27). Objections to the views expressed above are obvious. The coals are bituminous in the south-west, where the overlying strata is thickest; the igneous rocks of South Wales (Pembrokeshire) are of pre-Carboniferous age; the anthracites are not cleaved. Though the Pennsylvanian anthracites

are in a highly disturbed region, the seams of coal in the structurally complex regions in the north of France are not more anthracitized than those in less disturbed areas. In France it has been noticed that the deeper-seated seams are less bituminous than those above, a fact formulated and known as 'Hilt's Law,' to which, however, there are some noticeable exceptions in South Wales. Neither does Hilt's Law apply to the Midland Province in this country. For instance, in Yorkshire the Barnsley Coal is distinctly less bituminous than any of the underlying coals.

Crossing over to the west side of Carmarthen Bay, the general basin fold of the South Wales Coalfield is recogniz-

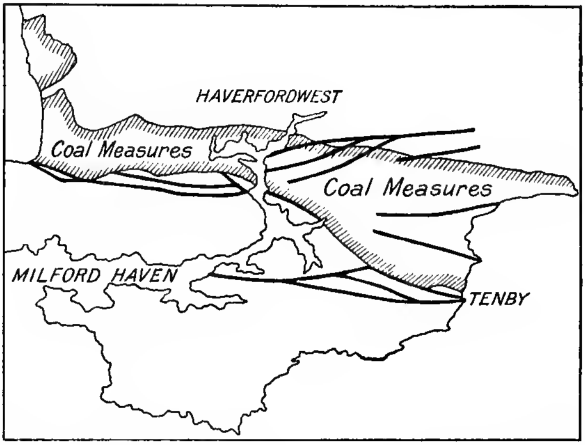


Fig. 22.—Sketch Map of the Pembrokeshire Coalfield. Scale, one inch=12 miles.

able; but while along the north crop the various subdivisions of the Coal-measures frequently occur in their normal sequence, in the central parts of the fold, and in a greater degree along the south crop, the orderly sequence is complicated by overfolding accompanied by numerous overthrust faults, which have the effect of reversing the normal dip of the Carboniferous strata into a southerly one, so that Coal-measures are found dipping under Millstone Grits, and these under the Carboniferous Limestone. In West Pembrokeshire the overthrust from the south has reached to such an intensity as to carry pre-Cambrian and Silurian strata on to the Coal-measures.

In West Pembrokeshire only the lower half of the Steam

Coal Series of Carmarthenshire and Glamorganshire is represented by a thickness of about 1,400 feet of measures. In this sequence the coal-seams occur in the following order: Farewell Rock, measures 30 feet; Tin Pits Vein, Lady's Frolick Vein, Kilgetty Vein, Catshole Vein, Lower Level Vein, Upper Garland Vein, Fiddler's Vein, Garland Vein, Rock Vein, Timber Vein, Low Vein, Rock Vein (of the Timber Vein Series), measures 360 feet. Correlation with individual seams on the east side of Carmarthen Bay is not possible. The Timber Vein is regarded as probably the same seam as the Stanllyd, the Rock Vein is comparable with the Big Vein, the Lower Level Vein with the Gwendraeth, and the Kilgetty Vein with the Pumpquart.

The seams from which most of the coal is obtained are the Rock Vein (2 feet to 4 feet 6 inches), Timber Vein (6 feet), Lower Level (about 2 feet and under), Kilgetty Vein (under 2 feet).

The structure of the coalfield consists of a central belt, ranging from Saundersfoot past Moreton and Jeffreston, and contains the nearest approach to an axis in the much dislocated main basin fold. This central region is bordered on the north by disturbances affecting the Old Red Sandstone, and on the south by a belt of overfolding and overthrusting of great complexity, in which the Coal-measures are involved. In the central belt the outcrops of the coal-seams appear to extend through a strip of narrow ground about one-half to one mile in width, and for about four and a half miles in length. In reality the numerous coal-seams at the surface do not represent a continuous series of coals dipping south, but are the outcrops of two or three veins repeated over and over again by overthrust faults arranged along a general line. The 'digging' or 'smutting' of the surface coal was an ancient industry, and probably accounts for the use in South Wales of the term 'vein' applied to a bed of coal, for old documents describe the coal as occurring as an 'ore coal,' a 'string,' and a 'slatch.' This practice of winning coal has long ceased, but witnesses of it remain in numerous deep depressions.

In West Pembrokeshire, owing to the complicated structure of the area, an accurately measured Coal-measure sequence is unobtainable, so that the following ascending order of the coals is open to correction: Farewell Rock, measures about 450 feet, Brawdy Lower and Upper veins, Throw Vein, Three Quarters or Triquart Vein, Five Feet

Vein (3 feet 6 inches), Stink or Migrement Vein, Yard Vein, Foot Vein, Quarry and Stonepit Vein (Sibbernock veins), Haggard Vein, Folkstone Vein, Folly Vein (4 feet), Hookes Vein, Cliff Vein (3 feet 6 inches), Black Cliff Vein, Ricketts Head Vein. Most of the seams are thin, and rarely exceed 2 feet in thickness. At present the workings are limited to a few shallow pits getting culm.

The seams are all anthracites, and the coal is frequently in the form of small coal (culm). An analysis of the Lower Level and Kilgetty veins gives: Carbon, 95·68; hydrogen, 3·04; oxygen, 0·51; nitrogen, 0·77; ash, 1·0. The Timber Vein shows a composition consisting of: Carbon, 94·72; hydrogen, 3·25; oxygen and nitrogen, 2·03; volatile matter, 4·74; ash, 0·8.

Forest of Dean Coalfield.

This coalfield, composed of entirely exposed Coal-measures, is usually regarded as an outlier of the South Wales Coalfield, from which it is separated by a broad expanse of Old Red Sandstone, broken through by the Silurian anticlinal inlier of Usk. It, however, shows many affinities with the Somersetshire coal-basin.

The Coal-measures occupy an area of thirty-four square miles. The available coal is estimated at 258,533,447 tons.

Resting conformably on the Old Red Sandstone, the Lower Carboniferous strata are succeeded unconformably by the Coal-measures. The following list gives the sequence of the formations in descending order:

			Thickness in Feet.
Upper Carboniferous	Coal-measures		1,400 +
Lower Carboniferous	Drybrook Sandstone		650 +
	Main Limestone	Whitehead Limestone	40–200
		Crease Limestone	75–100
		Lower Dolomite	250–400
	Lower Limestone Shales		190
	Old Red Sandstone.		

Coal is absent in the Lower Carboniferous strata, which contain important bodies of Brown Hæmatite. The Drybrook Sandstone, for a long time correlated with the Millstone Grit, is also without coal. A dolomite developed towards its centre carries deposits of Brown Hæmatite.

Resting unconformably on the Drybrook Sandstone, and consequently without the base being exposed, the Coal-

measures present the following descending sequence of coals:

Series	Strata	Ft.	Ins.
Upper Series of Coals	Measures	—	—
	Upper Woorgreens Coal	1	2
	Rock	24	0
	Lower Woorgreens Coal	1	9
Middle Series of Coals	Shale and rock	348	0
	Crow Delf Coal	1	3
	Shale	24	0
	Twenty Inch or Smith Coal	1	9
	Fireclay	3	0
	Foot Coal	1	3
	Shale	33	0
	Lowery Coal	2	1
	Shale	48	0
	Starkey Coal	1	7
	Shale	12	0
	Rockey Coal	1	8
	Shale and rock	42	0
	Breadless Coal	1	0
Lower Series of Coals	Shale	32	0
	Churchway High Delf Coal	1	11
	Rock and shale	93	0
	Brazilly Coal	1	9
	Shale and stone	159	0
	Yorkley Coal	2	1
	Rock	153	0
	Whittington Coal	1	9
	Rock	132	0
	Coleford High Delf Coal	4	3
	Rock	126	0
	Trenchard Coal	3	0
	Measures (not bottomed).		

Many of the coals of the Lower and Middle Series are extensively worked. The Coleford High Delf Seam, it will be observed, lies in the midst of a thick sandstone. It affords a well-known example of contemporaneous erosion in what is known as the 'horse.' This is a channel two miles long and from 170 to 340 yards in width cut in the coal, and subsequently filled in with sand-rock. The main channel is joined by smaller tributaries which run approximately parallel to it.

The Coal-measures of the Middle and Upper Series are noted for the number and excellent preservation of the fossil plants; specimens of *Pecopteris arborescens* and *Alethopteris serli* are particularly abundant. Palæobotanists consider that the whole assemblage indicates a high position in the Coal-measure sequence of this country.

Completely surrounded by the massive sandstones and

conglomerates of the Old Red Sandstone, the Carboniferous rocks of the Forest of Dean form an excellent example of a coal-basin formed by the deformation of a pre-existing hollow. Two well defined synclines—the Wigpool Syncline at the north-east extremity of the basin, and the Lydney Park Syncline at the southern end—break the symmetry of the original fold.

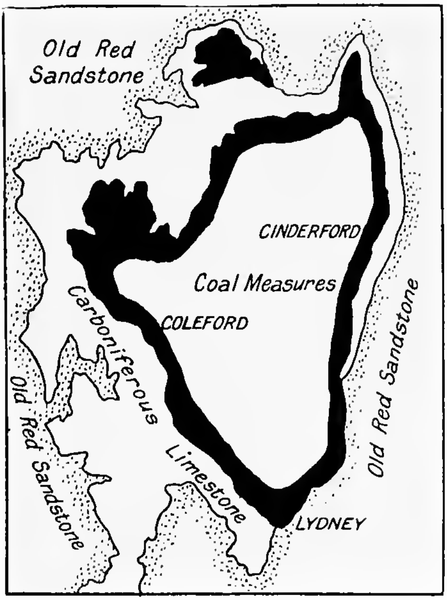


FIG. 23.—SKETCH MAP OF THE FOREST OF DEAN COALFIELD. Scale, one inch = 4 miles.

The seams at present worked are applicable to household, manufacturing, and gas-making purposes. It is thought, however, that unproved seams await development towards the centre of the basin, and that these will consist of drier coals than those in the beds above, but that large volumes of water, derived from the Pennant-like sandstone above the Trenchard and Coleford High Delf coals, would be encountered in sinking to them.

CHAPTER X

SOMERSET AND GLOUCESTER COALFIELDS

THE six detached areas of Coal-measures constituting these coalfields differ from those of South Wales and the Forest of Dean in that each area is surrounded almost entirely by strata newer than the Carboniferous formation. Indeed, coal-mining is carried on chiefly under the newer formations, and four-fifths of the coalfields belong to the concealed class. Excluding the Nailsea area, the exposed Coal-measures occupy 50 square miles, and that of the concealed Coal-measures has been estimated at 190 square miles. The coal-bearing districts are known as: (1) A southern area, giving a total thickness of 23 feet of coal; (2) a central area, containing thirty-five seams, with a united total thickness of 65 feet of coal; (3) a northern area, with seven seams of coal, giving a thickness of 10 feet of coal. The net available resources are estimated at 4,198,301,099 tons.

The faunal succession of the Lower Carboniferous rocks of the Bristol area affords the type development for Great Britain, and in the area round Radstock richly fossiliferous red measures with important workable seams of coal are considered by some geologists to represent the highest Carboniferous strata of the British Islands. It is certain that in the Radstock Series the workable coals belong to a high horizon, and are possibly on a level with the lower part of the Upper (Stephanian) Coal-measures of the Continent. The Keele Group of the Midland Province may correspond to the Radstock Series, but this group contains no seams of coal, and, unlike the Radstock Series, yields few fossils.

As in South Wales, the Coal-measures rest on a coarse gritty sandstone termed 'Millstone Grit,' as shown in the following table:

		Thickness in Feet.
Upper Series	Radstock Series, with workable coals	800
	Barren measures	550-750
	Farrington Series, with some workable coals - - -	500

		Thickness in Feet.
Middle Series	Pennant Sandstone, with occasional coals - - -	1,800–3,000
	Upper or New Rock Series, with many coals	1,700
	Lower or Vobster Series, with several coals	500
	Millstone Grit	500–1,000

In the Avon Valley the Carboniferous Limestone attains a thickness of 2,300 feet, and it has been estimated to reach a thickness of 3,000 feet in the region of the Mendip Hills. It has been systematically zoned by means of the corals and brachiopods; and the zones established in the Bristol area are applicable to other Lower Carboniferous regions in Great Britain. Descriptions of the coal-bearing Lower Carboniferous rocks of the North of England and Scotland frequently refer to the zones of the Bristol area. In ascending order the zones established are: (1) Lower Carboniferous Limestone or Tournaisian, with a zonal sequence of *Modiola, Cleistopora, Zaphrentis, Caninia ;* and (2) Upper Carboniferous Limestone or Viséan, with a zonal sequence of *Seminula Dibunophyllum* and *Posidonomya.*

The Limestone does not contain coal. Very little is known about the Millstone Grit Series, but it is apparently barren.

The Coal-measures are divided into two parts by a thick-bedded sandstone called 'Pennant Rock,' containing a few thin seams giving a total thickness of 5 feet of coal, one of which, known as 'Graces Coal,' has been worked in the Nailsea area, but on the whole the Pennant is a barren and heavily watered formation. Beneath the Pennant the measures are subdivided into a Lower or Vobster Group, corresponding to the Steam Coal Series of South Wales, and an Upper or New Rock Series, equivalent to the Lower Pennant or Red Ash Series of Glamorganshire. In each of the two groups of the Lower Series, owing to their occurring in isolated areas, it is impossible to correlate the strata of one district with that of another on the palæontological evidence at present available. The New Rock Series contains thicker and more numerous beds of sandstone than the Vobster Series. So far as is known, marine shells are confined to the Vobster Series, which also contains the more valuable seams of coal. The order of the coals in the New Rock and Vobster Series, for the two chief coal-producing

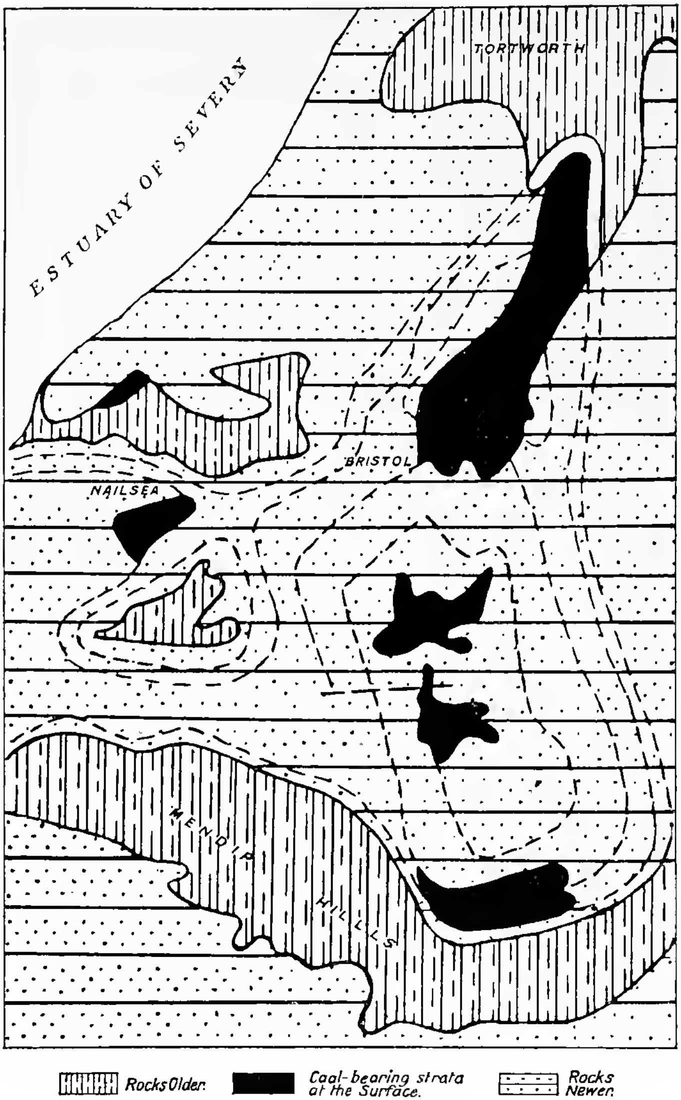


FIG. 24.—GEOLOGICAL MAP OF THE EXPOSED AND CONCEALED COALFIELDS OF GLOUCESTERSHIRE AND SOMERSETSHIRE (AFTER G. E. J. MCMURTRIE).

Scale, one inch = 4·16 miles.

districts, is given in the following list, but no correlation is implied:

Southern (Vobster) Area.

Globe.
Small Coal Vein.
Two Coal Vein.
Warkey Course Vein.
Garden Course Vein.
Strap Vein.
Great Course Vein.
Firestone Vein.
Little Course Vein.
Dunny Drift Vein.
Hard Coal Vein.
Perkin's Course Vein.
Foot Coal.
Branch Vein.
Golden Candlestick Vein.
North Shoots Vein.
South Shoots Vein.
Standing Vein
Fern Rag Vein.
Stone Rag.
Main or Callows Coal.
Strap Vein.
Perrink Vein.
White Axen Vein.
Red Axen Vein.
Wilmott's Vein.

Central (Bristol) Area.

Buff Seam.
Parrot Seam.
Little or Brimstone Seam.
Mixen Seam.
Stibb's First Seam.
Stibb's Second Seam.
Stibb's Third Seam.
Stibb's Fourth Seam
Stibb's Fifth Seam.
Hard Vein Seam.
Queen Bower Seam.
Doxall Seam.
Upper Five Coals or Rock Seam.
Primrose Seam.
Old Toad Seam.
Trow or Through Seam.
Red Ash Seam.
Hole or Hard Seam.
Five Coal Seam.
Thurfer Seam.
Kingswood Great Seam.
Giller's Inn Seam.
Little Toad or Two Feet Seam.
Parker's Top.
Parker's Middle.
Parker's Little.
Ashton Top.
Ashton Great.
Ashton Little.

In the isolated Nailsea basin the coals recognized beneath the Pennant in descending sequence are: Graces, Red Ash, White Top, Dungy, Under Little, Top Golden Valley, Golden Valley, Backwell Little, Smith's Coal, Dog Seam, Spider Delf, Crow.

Above the Pennant Sandstone two coal horizons are separated by from 500 to 700 feet of barren strata into a lower or Farrington Group, and into an upper or Radstock Group. In the Farrington an ascending order of seams includes the following: Seventeen Inches, Church Close or New Vein, Middle Seam, Peau or Peacock, Farrington Top, Cathead. Towards the middle of the barren strata separating the Farrington from the Radstock Series there occurs a group of red shales, from 130 to 150 feet thick, which is placed at the bottom of the Radstock Coal-measures. In the latter the coals are arranged in the following ascending

sequence: Nine Inches, Bull, Under Little, Slyving, Middle, Top Little, Great, Withy Mills.

Plant remains in an excellent state of preservation are abundant in the Coal-measures, particularly those in the Radstock Group.

Mollusca are rare, and the chief interest is attached to a marine bed, 20 feet thick, lying 120 feet above the top of the Millstone Grit at Ashton Vale Colliery, and about 200 feet above the Red Ash Coal of the same colliery. This bed has yielded thirty-eight genera and forty-seven species of marine invertebrata, chiefly dwarfed forms of lamellibranchs, gasteropods, and brachiopods, and others of rare occurrence in the British Coal-measures. The Cephalopods include *Orthoceras cylindricum, Pleuronautilus costatus, Temnocheilus* (*cf. tuberculatus*), *Glyphioceras diadema, Gastrioceras carbonarium, G. coronatum, G. listeri.* Shales with *Lingula* also occur on two horizons between this bed and the Red Ash Coal. Marine bands have been found in other localities, but the exact horizons have not been determined. Among the fresh-water lamellibranchs it is interesting to note the occurrence of *Anthracomya phillipsi, A. minima, A. lanciolata,* and *Naiadites elongata,* both in the measures below as well as in those above the Pennant Sandstone. Some of the commoner plants in the Radstock and Farrington Series are *Pecopteris arborescens, P. miltoni, P. oreopteridea, P. unita, Alethopteris serli, Sigillaria tessellata.* Of these, *Pecopteris arborescens* is recorded in the New Rock Series below the Pennant, but the other forms are absent; on the other hand, *Alethopteris lonchitica,* abundant in the Vobster Series, is unknown in the Radstock Group.

The Somersetshire and Gloucestershire coalfields form collectively an isolated basin surrounded by an uprise of Lower Carboniferous and Devonian rocks, but with their outcrops for the most part concealed beneath the secondary formations. At Kingswood an anticline accompanied by an east and west overlap fault separates the Somersetshire Coalfield on the south from the Bristol and Gloucestershire coalfields on the north. In the south and south-west the east and west Mendip anticline—or, more strictly speaking, anticlinorum, as the anticline is in reality built up of several folds—terminates the Somersetshire coalfield. Folds in the Lower Carboniferous rocks west of Bristol introduce the isolated coalfields of Nailsea ; and in the west and in the north Lower Carboniferous and older rocks rise from

beneath the Coal-measures on a line of uplift coincident with the Malvernian north and south axis. Thus two sets of folds meet within the coalfield. In the northern section of the coalfield the chief dislocations are four longitudinal faults traversing the district from north to south, and throwing up the measures to the west. In the southern or Somersetshire Coalfield faults are numerous, and on approaching the Mendip Hills the strata become overfolded and faulted to such an extent that the same seam may be passed through two or even three times in a single shaft. In some cases a seam is duplicated by an overfault. Along the Nettle Bridge Valley the Lower Coal-measures are completely inverted. Horizontal overthrust faults are also met with in the Radstock coal-basin, four miles north of the Mendip Hills. One of these, known as the Radstock overlap fault, causes a horizontal displacement of 420 feet in the Great Vein

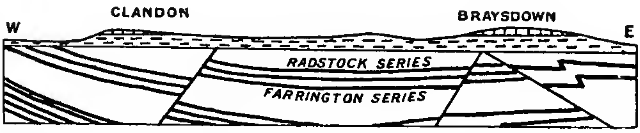


FIG. 25.—SECTION ACROSS THE RADSTOCK COALFIELD, SHOWING THE RADSTOCK OVERLAP FAULT (ON THE RIGHT) AND THE UNCONFORMABLE MESOZOIC COVER.

Coal, and 900 feet in the Bull Vein, 90 feet below the Great Vein. By some authorities this lateral movement is considered to have commenced before the deposition of the upper seams. Most of the folding and faulting was certainly completed before the deposition of the secondary rocks, which rest undisturbed on the tilted, dislocated, and denuded Coal-measures.

Of the coals given in the list, only a few have been worked. Many of them are thin (2 feet and under) or are composed of inferior coal, though thin seams, when of good quality, are worked to perhaps a greater extent than is usual in Great Britain. The highly inclined seams in the New Rock and Vobster Series are also a feature of the Radstock area. Smithy and coking coals are furnished by the Vobster Series, and house and manufacturing coals by the New Rock Series. The Ashton and Bedminster Great veins give coking, house, and manufacturing coals, having a large sale in the Bristol area. Similar kinds of coal are obtained from

the Five Coal, Great Vein, and Two Feet of Kingswood. Local swellings and 'swillies' or 'bladders' of coal are worked in the Pennant. Coals of the Farrington Group are all thin seams that are practically untouched, and, though less in number, are of good quality in the northern coalfield. The Radstock seams are extensively worked, and yield several classes of coal, including some second-class steam coal, but the thickest seam—2 feet 4 inches—is the Slyving.

The Kingswood Great Vein gives an analysis of: Carbon, 81·82; hydrogen, 4·63; oxygen, 5·54; nitrogen, 1·39; sulphur, 0·92; ash, 4·10; water, 1·60; and the Camerton Great Vein gives: Carbon, 81·64; hydrogen, 5·29; oxygen, 5·12; nitrogen, 1·46; sulphur, 0·67; ash, 4·10, water, 1·72.

Within the coal-basin the overlying Mesozoic rocks do not attain any great thickness, but outside the basin they may reach a united thickness of over 3,400 feet, distributed as follows: Trias, 2,000 feet; Rhætic, 50 feet; Lias, 1,200 feet; Inferior Oolite, 170 feet. South of the Mendip Hills a boring at Puriton, commencing in Keuper Marl, proved: Keuper Marl, 1,252 feet; Upper Sandstones, 202 feet; Pebble Beds, 14 feet; Lower Marls and Sandstones (Permian ?), to 582 feet. Over the northern part of Somersetshire the Lias has been laid down on an undulating surface, but it seldom exceeds 200 feet in thickness, and not more than this amount in the neighbourhood of the Gloucestershire Coalfield. Nowhere does the Lias in the vicinity of the coalfield reach 100 feet in thickness, and this and the Oolites are thin. At Hemington, two and a half miles south-south-east of Radstock, a boring proved Fuller's Earth, 87 feet; Inferior Oolite, 39 feet; Lias, 29 feet; Rhætic, 42 feet; Keuper Marl, 139 feet (on Coal-measures).

Extensions.—Of the partially exposed coalfields, that of Nailsea has an unproved extension to the south under the Triassic red marls and alluvial marshes; but as the coals in the Nailsea district vary in quality from place to place, the value of this unproved area remains uncertain. A buried coalfield also lies under the Severn in the neighbourhood of Weston. At Hemington, in an attempt to trace an extension of the Radstock Coalfield, the boring proved 864 feet of Coal-measures, consisting of purplish-red marl at the top, underlain by grey shale with abundant ironstone nodules, thick sandstones, fireclays, and thin coals up to 1 foot

in thickness. On the evidence of the plant remains, consisting among others of *Pecopteris cyathea, P. unita, P. miltoni, Alethopteris serli,* it has been concluded that the measures lie between the Radstock Red Shales and the Farrington coals. Therefore the Pennant Series and all the seams below should crop out under the Mesozoic formations much farther to the south-east of the boring. Since the Mendip anticlinorum of Lower Carboniferous rocks was raised after the deposition of the Coal-measures, it is possible that the Secondary rocks cover a coalfield to the south and south-east. Objections to this existence of coal south of the Mendip have been brought forward. One of these, though scarcely worth consideration, was based on an erroneous conception of the great unconformity between the Coal-measures and the newer formations. Since the newer formations on the southern slopes of the Mendip Hills rest on Lower Carboniferous or older rocks, it was inferred that the same relation would exist farther south; but a sharp fold over of the Lower Carboniferous strata would introduce the Upper Carboniferous rocks in a short distance south of the Mendips. An opinion receiving its chief support from the evidence of the fossil plants considers that, supposing such a sharp turnover takes place, this will introduce beds of the barren Upper Culm type of Devonshire. Recently the Devonshire Upper Culm measures, formerly regarded as of Lower Carboniferous age, have been found to contain a distinctly Upper Carboniferous flora, consisting of *Alethopteris serli, A. lonchitica, Mariopteris muricata, Lepidodendron obovatum, Sigillaria tessellata,* thus implying a Middle Coal-measure age, and probably not higher in the Somersetshire sequence than the Pennant Sandstone Group, a conclusion to some extent substantiated by the occurrence in the Upper Culm measures of *Gastrioceras carbonarium, G. listeri, Dimorphoceras gilbertsoni,* and *Pterinopecten papyraceus.* If, however, productive measures do exist south of the Mendip Hills, the depth to them is certainly great. A boring at Witham passed through 258 feet of Oxford Clay (sometimes recorded as Lias), 19 feet of Cornbrash, 24½ feet of Forest Marble, 131½ feet of Oolite, and 184 feet of Lias, in which it ended. A much earlier boring at Compton Dundon commenced in Keuper Marl, and was continued without success down to a depth of 519 feet. At Puriton a cover, as previously mentioned (p. 138), exceeding 2,050 feet in thickness, without

reaching Carboniferous rocks, was encountered in a boring for coal. The poverty in coal-seams of the northern part of the Gloucestershire Coalfield does not favour explorations outside the margins of the exposed coalfield. A recent trial-hole at Winterbourne, six miles north-east of Bristol, shows that while coal-seams are present, they are thin and of inferior quality. This boring proved Keuper Marl, 17 feet; Pennant Sandstone, 883 feet; Lower Coal Series, 1,437 feet. Of four marine bands, occurring in smooth sandstone and soapy shale, between the depth of 1,090 and 2,000 feet, the one at 2,000 feet contained *Ambocœlia carbonaria*, *Chonetes hardrensis*, *Chonetes languessiana*, *Lingula mytiloides*, *Nuculana attenuata*, *Schizodus antiquus*, and *Productus*, a fauna reminiscent of the marine band above the Millstone Grit of Ashton Vale.

About midway between the north and south axis of the northern part of the Gloucestershire coalfield, and a prolongation of the north-west to south-east fold of the Warwickshire productive Coal-measures, two borings at Batsford and Burford have both proved Coal-measures under a cover of Mesozoic rocks. At Burford, 17 miles north-north-west of Oxford, Coal-measures were proved at 834 feet below Ordnance datum, under a cover consisting of Oolite, 90 feet; Lias, 627 feet; Trias, 467 feet. In the Batsford (Lower Lemington) boring, 14 miles nearly due north of Burford, Coal-measures were reached at 641 feet below Ordnance datum under a cover of Lias, 418 feet; Trias, 603 feet. The Burford boring penetrated Coal-measures containing one thin coal through a thickness of 226 feet, and ended in Coal-measures. At Batsford 524 feet of Coal-measures resting on Silurian were proved. In descending order the Coal-measures consisted of grey shales and sandstones, with ostracod limestone, 133 feet; sandstone resembling Pennant, 226½ feet; grey and red shale, 61½ feet; sandstone and conglomerate, 103½ feet. To what part of the sequence the Coal-measures of Burford belong is uncertain. Those of Batsford recall the Etruria Marls and Halesowen Sandstones of the Warwickshire Coalfield, with a marginal development of Middle Coal-measures represented by the sandstones and conglomerates occurring below the red shales.

At present these two borings supply the only evidence of the character of the Palæozoic floor over an area of more

than 800 square miles between the Severn on the west and the valley of the Cherwell on the east. East of the Cherwell the Palæozoic floor has been proved at Bletchley, Calvert, and in some borings near Northampton. At Bletchley, under a cover consisting of Oxford Clay, 192 feet; Forest Marble, 33 feet; (Great Oolite, absent); Lias, 185 feet; rocks older than the Carboniferous formation were reached. Similarly at Calvert, the Carboniferous rocks were proved absent, under a slightly different cover, composed of Oxford Clay, 93 feet; Forest Marble, 38 feet; Great Oolite, 66 feet; Lias, 240 feet. Carboniferous Limestone resting on pre-Cambrian rocks was struck in a boring at Orton, Northampton. An eastern boundary can therefore be drawn provisionally along the Cherwell Valley.

Returning to the Batsford locality, it is significant to note that it lies on the south-easterly prolongation of the main structural feature of the South Staffordshire Coalfield, as indicated in the Silurian uplift of Dudley and the Siluro-Cambrian ridge of the Lickey Hills. Productive measures wrap round the Dudley anticline, and Upper Coal-measures rest on the pre-Carboniferous rocks of the Lickey Hills. Farther east, at Binley Colliery, at the south-eastern prolongation of the Warwickshire Coalfield, the productive measures plunge steeply westwards off the pre-Cambrian shales and quartzites that extend along a ridge parallel to that of the Lickey Hills. This high dip quickly brings in the great thickness of Upper Coal-measures of Coventry that extend southwards to near Warwick, twenty miles north of Batsford. It is, therefore, not improbable that borings near Kineton and to the north would reach productive Coal-measures under a cover of the Liassic and Triassic formations. Around Stratford-on-Avon the Keuper Marl has been proved to have a thickness of 604 feet, and the Triassic sandstones beneath have been penetrated for a thickness of 205 feet. At Rugby, twenty miles north-east of Stratford-on-Avon, a boring proved: Lias, 458 feet; Keuper Marl and Rhætic, 672 feet. South of Rugby and east of Stratford-on-Avon there is no direct evidence on which to base an estimate for the Lias and Trias, but the latter shows a marked attenuation to the south-east, and is feebly represented or is absent in the borings east of the Cherwell Valley. A boring commencing in Lias, north of Kineton, should reach the Palæozoic floor within a maximum depth

of 1,500 feet, and probably not much exceeding 1,000 feet from the surface. It remains uncertain whether the Coal-measures, supposing them to be present, would occur in a productive form, and whether the character of the seams would resemble those of the Gloucestershire Coalfield or those of the Warwickshire Coalfield.

CHAPTER XI

THE EAST KENT COALFIELD

The great east and west disturbance which traverses the south of Ireland, South Wales, Devon, and Somerset disappears eastwards under the Secondary formations of the southern counties, to appear again in the north of France and Belgium. Involved in this folding lie the

MESOZOIC FORMATIONS.

			Thickness in Feet.
Cretaceous	Chalk		650 (W.) to 900 (E.)
	Selbornian	Upper Greensand, Gault	244 (W.) to 63 (E.)
	Lower Greensand	Folkestone Beds, Sandgate Beds, Hythe Beds	30-40 (N.) to 210 (S.)
		Atherfield Clay	20 to 43
	Weald Clay	-	720 (W.) to 15 (E.)
	Hastings Beds	Upper Tunbridge Wells Sand, Grinstead Clay, Lower Tunbridge Wells Sand	150 to 180
		Wadhurst Clay	160 to 235
		Ashdown Sand	300 to 681
Jurassic	Purbeck Beds		up to 562
	Portland Beds	-	14 to 131
	Kimmeridge Clay -		up to 622
	Corallian Beds		,, to 342
	Oxford Clay		,, to 243
	Great Oolite		,, to 189
	Lias		,, to 173
	Trias	- -	0 to 81

exposed coalfields of South Wales, Forest of Dean, and Bristol in the west, and in the east lie the coalfields of the Boulonnais, Pas de Calais, Liége, and the Dutch Campine. Summing up the opinions of leading geologists, Prestwich, writing in 1870, says: 'We ourselves have no doubt not only of the possibility, but of the high probability, of the existence of similar basins under the Secondary and Tertiary formations of the south of England.' Step by step these

anticipations have been realized in the now well-known concealed coalfield of Kent, but with its boundaries so ill-defined that in 1905 it was found impossible to make any estimate of the amount of coal likely to exist, though recently computed at over 2,000,000,000 tons.

The area of the concealed Kent Coalfield, proved or partially proved, has been estimated at 206 square miles, of which 150 square miles are on land, and 56 square miles under the sea beneath a cover of Cretaceous and Jurassic rocks, but little exceeding 1,000 feet in thickness.

The formations beneath which the Carboniferous rocks lie concealed, excluding a small thickness of Tertiary strata, are given on p. 143.

These formations are not present at any one spot, nor does a boring or shaft commencing in the Chalk formation necessarily pass through all the underlying groups given in the table; thus the boring at Ebbsfleet, north of Sandwich, under 110 feet of superficial and Tertiary rocks, passes down to the Carboniferous floor through 785 feet of Chalk, 110 feet of Gault, 36 feet of Folkestone and Sandgate Beds, 15 feet of Weald Clay, which rests on the Coal-measures; the Mesozoic formations below the Weald Clay being absent. At Dover, on the contrary, the formations under the Chalk consist of: Gault, 135 feet; Folkestone and Sandgate Beds, 87 feet; Atherfield Clay, 43 feet; Weald Clay, 50 feet; Hastings Beds, 35 feet; Purbeck Beds, absent; Portland Beds, absent; Kimmeridge Clay, 44 feet; Corallian, 310 feet; Oxford Clay, 88 feet; Kellaway's, etc., 66 feet; Great Oolite, 69 feet; Inferior Oolite, 27 feet; Lias, 38 feet. At Brabourne, 13 miles west of Dover and 19 miles south-west of Ebbsfleet, a boring commencing in Gault penetrated, and after passing through 72 feet of this clay proved an underlying sequence of Folkestone and Sandgate Beds, 210 feet; Atherfield Clay, 21 feet; Weald Clay, 109 feet; Hastings Beds, 200 feet; Purbeck Beds, 78 feet; Portland Beds, 31 feet; Kimmeridge Clay, 262 feet; Corallian Beds, 342 feet; Oxford Clay, 173 feet; Kellaway's, etc., 31 feet; Great Oolite, 137 feet; Inferior Oolite, 44 feet; Lias, 140 feet; Trias, 81 feet. Farther west, at Battle, two and three-quarter miles east-south-east of the well-known sub-Wealden boring, there has been proved a thickness of: Hastings Beds, 424 feet; Purbeck Beds, 387 feet; Portland Beds, 141 feet, and 1,114 feet of Kimmeridge Clay, in which the boring ended. At Penshurst the united thickness of the

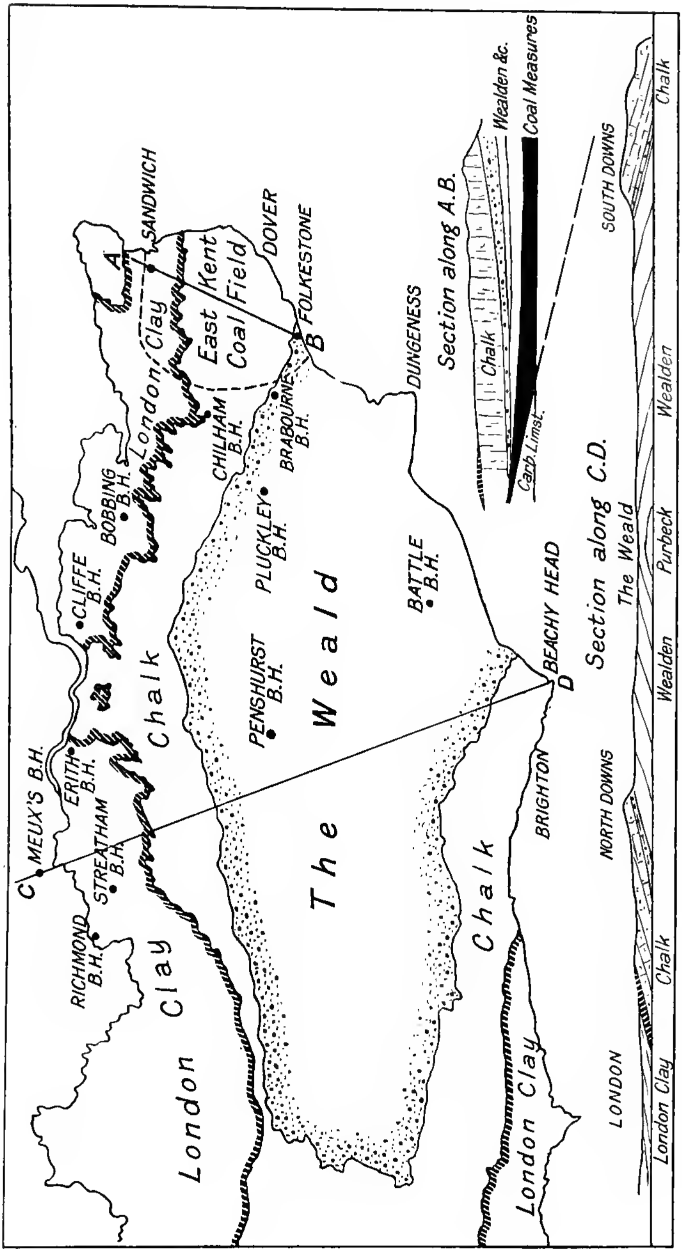


Fig. 26.—Sketch Map of the Weald.
Scale, one inch = 22 miles.

Hastings, Purbeck, Portland, and Kimmeridge Clay amounts to over 1,800 feet, and at Pluckley to over 1,600 feet, including 680 feet of Weald Clay, both borings ending in Kimmeridge Clay. It is evident, then, that the cover increases to the west and south-west. For this reason shaft-sinkings and borings have been confined to East Kent.

The number of the explorations in East Kent amounts to over thirty, and though some do not reach the Palæozoic floor, many do so (Fig. 27, p. 150), and thus afford sufficient evidence on which to base conclusions as to the general relation between the Palæozoic floor and the covering formations, and how the latter are arranged. It has been noticed that the Jurassic and Lower Cretaceous rocks form a composite wedge thrust in, as it were, between the Upper Cretaceous rocks and the Palæozoic platform on which the Mesozoic rocks repose (Fig. 26, p. 145). The thin edge of the wedge lies in the north-east near Ebbsfleet, where, as previously stated, only 51 feet of Lower Cretaceous rocks are present between the Gault and the Carboniferous strata. Proceeding southwards, the Lower Cretaceous rocks, though with some irregularities, increase in thickness and continue to form the top layer of the wedge, but beneath it the several members of the Jurassic formation come in, in turn, one after another until in the Elham Boring, sixteen miles south-west of Ebbsfleet, no less than 1,200 feet of Jurassic rocks intervene between the Gault and the Palæozoic platform.

In the Battle Boring, however, the united thickness of the Purbeck and Portland Beds amounts to 528 feet, as compared with 1,117 feet at Penshurst, to the north of Battle, suggesting that the Jurassic rocks wedge out under the southern side of the Weald as they do on the north. As regards the Ebbsfleet and Elham borings it will be noticed that while the first, commenced in the Tertiary formation, and passed through the whole of the Chalk formation, yet Elham, commencing near the base of the Chalk, reached the Palæozoic floor at the greater depth.

Explorations for coal, therefore, in Kent differ from those in Nottinghamshire and Yorkshire (p. 192), where the Trias formation keeps on increasing in thickness eastwards, and should it diminish farther east, this will only have taken place beyond the eastern limit of the concealed Nottinghamshire and Yorkshire Coalfield.

The composition of the Chalk and its water-bearing

capacity are too well known to need a description. The Gault is a dead, stiff, blue clay, sometimes sandy or calcareous. In some localities in the west of the county, thin beds of sand, nowhere more than 12 feet in thickness, overlie the clay, and are known as the Upper Greensand formation. The Lower Greensand and Wealden are chiefly arenaceous deposits with some clay. Beneath this sandy series the strata, as regards boring or sinking operations, consist of limestone (Corallian), with clay (Kimmeridge Clay) above it and clay (Oxford Clay) below it. The Lower Oolites are essentially calcareous formations with basal sandy beds from 0 to 40 feet in thickness. Thickest in the east, the basal sandy beds thin out northwards and become intercalated with sand, limestones, and bands of shale westwards and south-westwards.

The Mesozoic formations rest with a striking unconformity on the Palæozoic rocks. This unconformity is as great as that between the Mesozoic and Palæozoic rocks around the Somersetshire Coalfield. In East Kent the Palæozoic platform, on which the Secondary formations were deposited, appears to have been a gently undulating surface sloping on the whole to the south-west and west, reaching its highest elevation (– 800 feet OD in the east near Ripple and Deal), and falling to below – 1,200 feet OD at Ellinge, and to – 1,400 feet OD at Folkestone. The fall between Deal and Folkestone is therefore 600 feet in thirteen miles, or at the rate of 46 feet per mile in a general south-westerly direction. So far the Palæozoic platform reached in borings betrays no indications of warping or of deeply eroded hollows, such as occur in the buried central Midland coal-basin; and its contour resembles that of Nottinghamshire and South Yorkshire, though in Kent the general slope is to the west and south-west, whereas in the East Midlands the Palæozoic platform inclines to the east and north-east.

The Secondary formations of the south-east of England are, as is familiarly known, arched up into the Wealden dome, situated between the North and South Downs, with its denuded crest along the centre of the Weald. It will be seen that the early borings for coal were located near this crest, under the impression that the Coal-measures, supposing them to exist, would be reached at a shallower depth than borings situated away from the axis of the dome and commencing in newer formations. It has been

shown that the superficial anticline of the Weald is superimposed upon a syncline of deeper-seated Mesozoic rocks.

The Coal-measures in East Kent are proved to consist mainly of grey sandstones, grey and dark-coloured shales, fireclays, and numerous seams of coal—mostly thin and divided by partings, but occurring at intervals throughout the sequence. Red sediments are markedly scarce, and have been found only in the Folkestone Boring, in which some greenish-grey shales, 87 feet thick, and described as 'red in places,' occur under some 600 feet of grey Coal-measures.

It is considered that between 3,700 feet and 4,000 feet of Coal-measures have been proved. Somewhat divergent opinions are held as to their classification. Lithologically, the sequence shows a greater resemblance to the New Rock Series and Pennant Series of Somersetshire than it does to the Middle Coal-measures of the Midland Province. Each of the several borings reaching Carboniferous Limestone in the north and east prove the absence of grit beds in Kent resembling the Millstone Grits of Somersetshire, the Coal-measures in each case resting on limestone. This limestone seems to represent the lower part of the *Dibunophyllum* zone of the Avonian sequence, so that apparently the highest beds of the Carboniferous Limestone, as well as the Millstone Grits, are missing in Kent. Whether the Lower Coal-measures are also represented is in dispute.

Though the coals are somewhat evenly distributed throughout the measures, it is concluded that there is a lower group separated by a varying thickness (up to 800 feet) of comparatively barren measures from an upper group of coals that are worked at Tilmanstone and Snowdown collieries. The thickest coals are in the lower group, and are reported to reach a thickness of 11 feet or more; but no one has yet put forward a correlation of the seams found in the several explorations. The Beresford Seam (4 feet 4 inches) at a depth of 1,490 feet, is correlated with a 6-foot seam of the Barfrestone Boring. At Snowdown it has a shale parting. The coal above this band gives an analysis of: Fixed carbon, 63·14; volatile matter, 27·98; sulphur, 1·32; ash, 7·20; moisture, 1·68; coke, 70·34. Below the band: Fixed carbon, 63·65; volatile matter, 28·26; sulphur, 1·29; ash, 6·11; moisture, 1·98; coke, 69·76. At the same colliery a seam (Snowdown Hard), at a depth of 2,236 feet, and considered as the same seam, 4 feet 7 inches thick at Barfrestone, gives an analysis of: Fixed carbon, 71·21;

volatile matter, 23·29; sulphur, 0·95; ash, 4·45; hygroscopic moisture, 1·05; coke, 75·65. Below this coal, at 3,007 feet depth, a bed of solid coal, 4 feet 5 inches thick, gives an analysis of: Fixed carbon, 75·65; volatile matter, 20·97; ash, 2·55; moisture, 0·83. At Tilmanstone Colliery a coal, called the Five Foot Seam, gives an analysis of: Carbon, 79·12; hydrogen, 4·66; oxygen, 5·90; nitrogen, 1·13; sulphur, 2·30; ash, 5·87; hygroscopic moisture, 1·02.

The Coal-measures of Kent are, as a rule, rich in fossil plants, evenly distributed. Over ninety-six species are known to occur, and they afford sufficient evidence, so palæobotanists claim, to conclude that the Lower Coal-measures are wanting, and that the Middle Coal-measures graduate upwards into a Transition Series (lower part of the Upper Coal-measures of the Southern and Midland Provinces). According to the plant evidence, the coal worked at Tilmanstone is placed in the Transition Series, which on the same grounds exceeds 1,800 feet in thickness in the Folkestone Boring. In the Bere Farm Boring, one and three-quarter miles north-east of Dover, grey sandstone and shale between 1,864 feet and 2,085 feet depth, and occurring beneath black shales with several coals, have yielded the following plants: *Sphenopteris* (*cf. neuropteroides*), *Pecopteris* (*cf. unita*), *P. miltoni*, *P.* (*cyatheites*) sp., *Alethopteris davreuxi*, *Neuropteris macrophylla*, *N. scheuchzeri*, *N. ovata*, *N. rarinervis*, *Odontopteris lindleyana*, *Annularia stellata*, *Cordianthus*, *Palæostachya elongata*, *Sphenophyllum emarginatum*, *Stigmaria ficoides*, *Samaropsis arberi*. The beds containing these plants have been referred by Dr. Kidston to the Keele (Radstock) Group. This would give over 7,000 feet of coal-measures occurring above the Transition Series at Bere Farm.

The fauna of the Kent Coal-measures is not so rich as the flora, in this respect agreeing with the Somersetshire Coal-measure sequence. The vertical range of the fauna in the following borings suggests a lower subdivision with one or more marine bands, and an upper subdivision in which marine beds are absent.

Boring.	*Upper Division.*	*Lower Division.*
Barfrestone	1,426	539
Oxney	202	771
Mattice Hill	356	703
Ripple	1,086	843
Walmestone	634	670

The marine beds contain a fauna consisting of *Lingula mytiloides*, *Orbiculoidea nitida*, *Productus scabriculus*, *P. longispinus*, *Nucula æqualis*, *N. luciniformis*, *Nuculana attenuata*, *Edmondia accipiens*, *Ctenodonta lævirostris*, *Protoschizodus curtus*, *Sanguinolites interruptus*, *Euphemus urei*, *Goniatites* sp., *Orthoceras* (*cf. cylindraceum*).

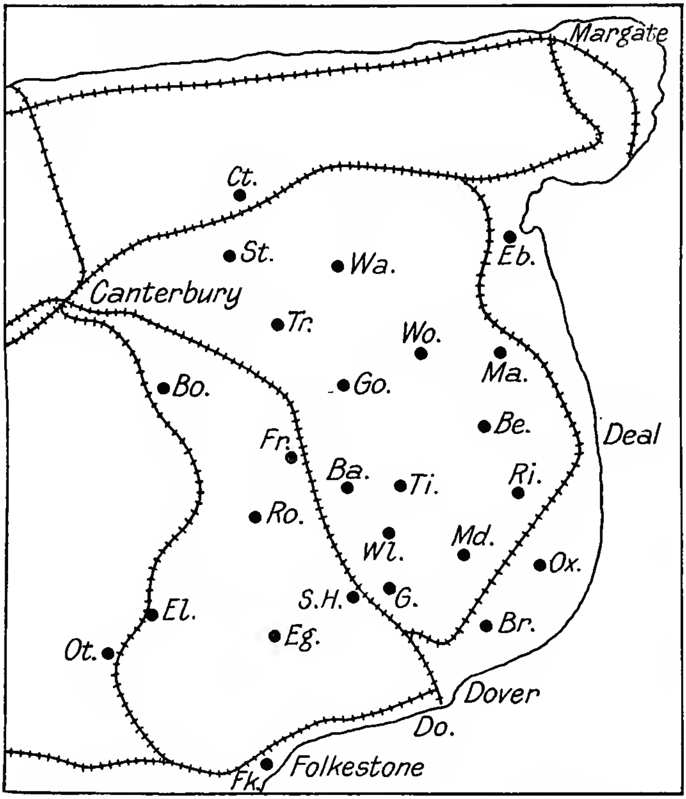


Fig. 27.—Explorations for Coal in East Kent.
Scale, one inch = 5 miles.

Ba. Barfreston.
Be. Betteshanger.
Bo. Bishopbourne.
Br. Bere Farm.
Ct. Chislet (shaft).
Do. Dover (shaft).
Eb. Ebbsfleet.
Eg. Ellinge.
El. Elham.
Fk. Folkestone.
Fr. Fredville.
G. Guildford (shaft).
Go. Goodnestone.
Ma. Mattice Hill.
Md. Madensole.
Ot. Ottinge.
Ox. Oxney.
Ri. Ripple.
Ro. Ropersole.
S.H. Stone Hall.
St. Stodmarsh.
Ti. Tilmanstone (shaft).
Tr. Trapham.
Wa. Walmestone.
Wl. Waldershare.
Wo. Woodnesborough.

In Kent *Anthracomya phillipsi* occurs in the Upper and Lower Series, as also does *Naiadites carinata*, but *Anthracomya wardi* has been found only in the Upper Series. The absence of *Carbonicola robusta* is noteworthy, and suggests that Lower Coal-measures do not occur in Kent. Negative evidence in boring, however, is not a reliable guide.

The vertical distribution of the fauna and flora indicates, as in other British coalfields, only thick zones, and emphasizes the difficulty of recognizing positions in the Coal-measure sequence in the absence of one or more definite bands possessing distinctive lithological and palæontological characters.

Descriptions of some of the borings suggest faulting, but what is the internal structural character of the coalfield awaits further colliery development. At Tilmanstone Colliery the dip is 1 in 17 in a direction 35 degrees west of south; at Snowdown Colliery it is 1 in 23 in a direction 70 degrees east of north. Igneous rocks are absent, and structurally the Kent Coalfield lies within the Southern Province of the British coalfields.

An approximate contoured outline of the Palæozoic platform is obtainable by the three-point method on the data given on the map and the table of depths. Such contours are necessarily only rough approximations, and though they are perhaps not so regular as those of the buried Palæozoic platform in Nottinghamshire and Yorkshire (p. 192), they certainly bring out the fact that the platform is far less rugged than that in the central Midland Province. The average rate of fall is 46 feet per mile in a direction west-south-west for the central and southern parts of the area. A low ridge lies in the north, with a fall to the north-east at a rate of roughly 60 feet per mile.

The northern boundary of the coalfield has been located within approximate limits by the borings (in table on p. 151), which have proved Coal-measures resting on Carboniferous Limestone. The coalfield, unless the measures come in again to the north through faulting or a roll-over of the Carboniferous, terminates north of Ebbsfleet and Stodmarsh. The eastern boundary is less defined, but that it extends beyond the coast-line will be gathered from the Mattice Hill (Sandwich), Betteshanger, Ripple, and Oxney bore-holes. The southern boundary probably stretches far out under the Channel, judging from the high Coal-measures found in the Bere Farm Boring, in the Dover shafts, and

at the Folkestone Boring. No accurate information is available to locate the western boundary; but in borings at Brabourne and Chilham the Mesozoic formation rests on rocks older than the Carboniferous strata.

SOME BORINGS IN EAST KENT.

Borings (OD in Feet).	*Reach Coal-measures (–OD in Feet).*	*Reach Carboniferous Limestone (–OD in Feet).*	*Thickness of Coal-(measures proved).*
Barfreston (193) ..	1,031	—	+2,103
Bere Farm (396) ..	962	—	1,647
Dover (shafts)	1,100	—	+1,170
Ebbsfleet (10)	1,046	1,149	103
Ellinge	1,286	—	—
Elham (1,275)	1,323	1,014	691
Folkestone (113) ..	—	—	1,913
Fredville (259) ..	1,116	—	+460
Goodnestone (136) ..	1,052	—	+1,718
Guildford shaft (365) ..	—	—	—
Maydensole (253) ..	941	—	+2,565
Mattice Hill, Sandwich (11)	964	2,040	1,076
Oxney (138)	859	3,564	2,705
Ropersole	1,180	—	520
Ripple (68)	808	3,096	2,288
Stodmarsh (87) ..	979	2,054	1,076
Tilmanstone (shafts, 225)	947	—	—
Trapham (Wingham, 59)	1,065	2,717	1,652
Woodnesborough (51)	1,017	2,566	1,549
Walmerstone (74) ..	1,002	2,203	1,201
Waldershare (335) ..	1,059	—	+1,469

Whether concealed Coal-measures are present at workable depths or are absent to the west of the Brabourne-Chilham platform and north of the proved Kent Coalfield has been partly proved by the borings listed on p. 153, in each of which Coal-measures proved to be absent.

Penshurst and Pluckley show that if the Coal-measures exist they lie at great depths; while the other borings (Brabourne and Chilham) prove them absent. Indeed, in borings north of the Thames the Mesozoic formation rests directly on rocks older than the Carboniferous formation, with the exception of borings near Northampton.

BORINGS OUTSIDE THE PROVED COALFIELD.

Boring (OD in Feet).	*Depth in Feet.*	*Remarks.*
Bobbing (120)	1,190	Oolite on Devonian.
Cliffe	1,037	Greensand on Silurian.
Crossness (6)	1,060	Gault on Devonian.
Erith	1,008	Gault on Devonian.
Little Missenden (459) ..	1,200	Reached Silurian.
Kentish Town (186) ..	1,302	Gault on Devonian (?)
Meux's (85)	1,064	Lower Greensand on Devonian.
Penshurst (100)	1,860	Ended in Kimmeridge Clay.
Pluckley (105)	1,718	Ended in Kimmeridge Clay.
Richmond (144)	1,237	Great Oolite on Devonian (?).
Streatham (110)	1,271	Jurassic on Devonian (?).
Sub-Wealden (300) ..	1,905	Ended in Oxfordian.
Turnford (110)	1,010	Gault on Devonian.
Ware (110)	831	Ended in Silurian.

CHAPTER XII

THE COALFIELDS OF NORTH STAFFORDSHIRE

It is generally accepted that over an area exceeding 10,000 square miles in the Midland Counties the Coal-measures were laid down in an almost continuous sheet, extending from the Welsh hills and Irish Sea on the west to the borders of the North Sea on the east, and possibly beyond. It is also agreed that this area was originally connected on the north with the Durham coal-basin, and that on the south the minimum of deposition was reached along the borders of a tract of elevated land, of which the Malvern and Lickey Hills, the Nuneaton Ridge, and Charnwood Forest form visible peaks.

As a whole, the area was undergoing depression throughout Carboniferous times. At its close a period of active earth movement ensued, and the recently formed Carboniferous sediments were bent into alternating elevations (ridge folds) and depressions (basin folds).

These tectonic movements proceeded along two lines. A thrust from the east buckled the Carboniferous strata into a number of folds having their axes directed north and south or north-east and south-west. Of these folds, those forming the composite Pennine anticlinal resulted in the most important change, since they lead to the separation of the eastern (Nottinghamshire and Yorkshire) basin from the western (Cheshire) basin.

Simultaneously, or possibly in part successively, a series of east and west transverse folds were produced by a creep from the south; one of these, stretching from Pendle Hill, in Lancashire, eastwards along the valley of the Wharfe, divided off the coal-basin of the northern counties from the Midland basin on the south.

Another east and west anticlinal ridge in the latitude of Stone, Castle Donnington, and Ruddington, divides the eastern Midland basin into two unequal portions—a northern half containing the coalfields of the Yorkshire, Derbyshire,

and Nottinghamshire basin, and a southern half containing the coalfields of the Leicestershire platform.

The term 'Midland Coal-basin' is applied to the area of Carboniferous strata defined by these post-Carboniferous movements.

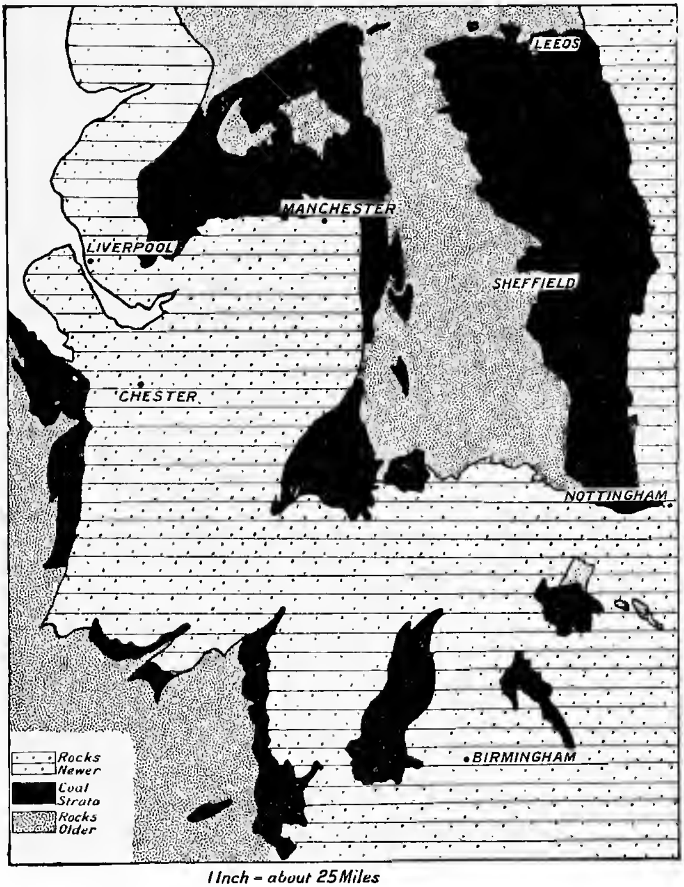


FIG. 28.—THE COALFIELDS OF THE MIDLAND BASIN.

During the period of the earth movement an immense quantity of material was swept away from the crests of the ridge folds, amounting to as much as 8,000 feet of Carboniferous strata near Harrogate. On the other hand, the strata in the basin folds were preserved from denudation;

and it is these that now constitute the concealed and partly concealed coalfields.

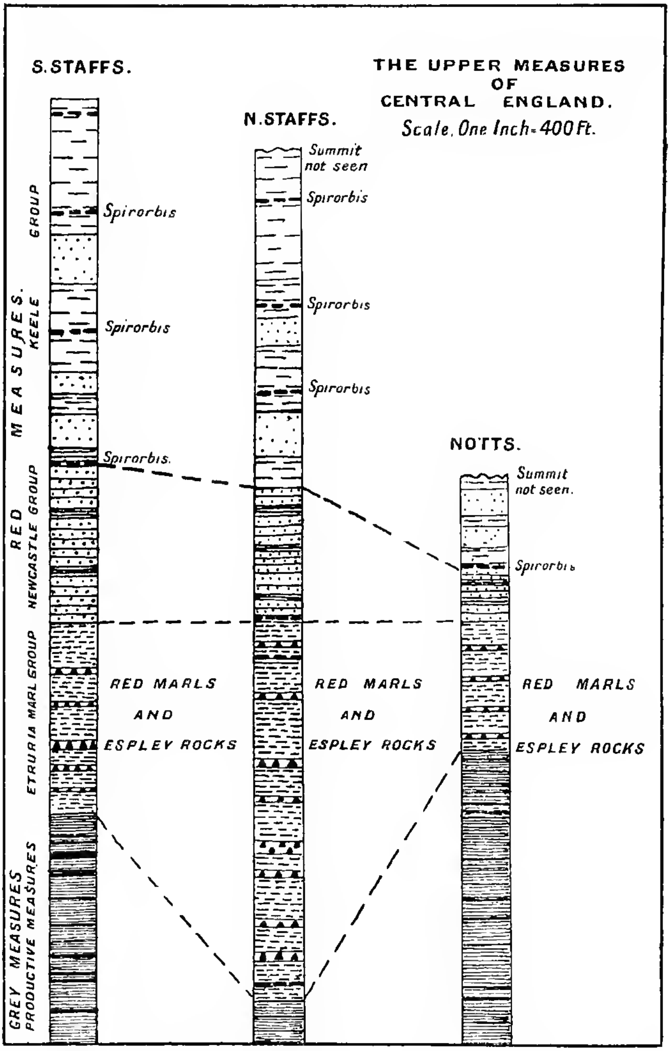


FIG. 29.—THE RED-AND-GREY SERIES OF THE MIDLAND BASIN.

At a much later period the Midland area became covered by the deposits of the Permian and Triassic formations, and subsequently by the later Mesozoic sediments, which buried

up the highly inclined and eroded edges of the Carboniferous rocks.

The Mesozoic cover was in turn denuded off the crests of the anticlines, but has to a great extent escaped destruction over the synclines.

In this way the discontinuity of the Carboniferous areas caused by pre-Permian folding and denudation has been accentuated and the present outlines of the visible coalfields determined.

The separated coalfields group themselves in relation to the Pennine, Stone, and Castle Donnington anticlinals.

North of the Stone-Castle Donnington anticline we have on the east of the Pennine anticlinal the large coalfields of Derbyshire, Nottinghamshire, and Yorkshire; on the west of the anticline we meet with the coalfields of North Staffordshire, Lancashire, and North Wales.

South of the Stone-Castle Donnington anticline lie the coalfields of Coalbrookdale, South Staffordshire, Warwickshire, and Leicestershire.

Geologists are as yet far from agreed as to the nomenclature suitable for the different subdivisions. Locally the Keele, Newcastle, and Etruria Marl groups are termed Upper Coal-measures, but Mr. Kidston, from palæobotanical evidence, considers that the Keele Group alone represents the Upper Coal-measures of Continental geologists, and for the two remaining groups he has suggested the term 'Westphalian' for the Middle Coal-measures, and 'Lanarkian' for the Lower Coal-measures.

THE CARBONIFEROUS SEQUENCE IN THE MIDLAND BASIN

Divisions and Subdivisions.		*Thickness in Feet.*	
		Central and North.	*South.*
Upper	Hamstead Group (? Carboniferous)	Absent (?)	2,000
	Keele Group	700	700
	Newcastle or Halesowen Group	350	400
	Etruria Marl Group	1,100	0 to 400
	Middle Coal-measures ..	6,000	800
	Lower Coal-measures ..	2,000	Absent (?)
	Millstone Grit Series ..	1,000	Thin or absent
Lower	Carboniferous Limestone Series	2,000 +	Thin or absent

In the following pages the terminology in general use is adopted, and the distinguishing characters of the divisions and subdivisions mentioned for each coalfield.

From the Millstone Grits upwards each break in the regular continuity of the sequence which may occur is only local. The Keele Group (so-called Permian) has not been determined in all the coalfields, and the top beds of the so-called Permian of the Warwickshire and Shropshire areas is possibly of post-Carboniferous age and slightly unconformable to the Coal-measures.

The Lower Carboniferous rocks and the Millstone Grits, with a few exceptions, do not contain workable seams. The chief coals are universally met with in the Middle Coal-measures. The Etruria Marl, Newcastle, and Keele groups are without workable seams. The covering formations newer than the Carboniferous occur in fullest sequence in the Yorkshire basin, but the Triassic strata are thickest over the Cheshire and Staffordshire basins.

The following table gives the sequence and maximum thickness of the Secondary rocks within the limits of the proved basin:

SECONDARY FORMATIONS OF THE MIDLAND BASIN.

(THICKNESSES IN FEET.)

Formation.	*North-West.*	*South-West.*	*North-East.*	*South-East.*
Triassic Marls ..	2,000–3,000	1,000	900	700
Trias Sandstones	2,600	1,200	1,200	300
Permian ..	1,500	700	1,000	Absent

NORTH STAFFORDSHIRE COALFIELD.

This triangular-shaped coalfield includes an area of about 100 square miles, and affords the type region for the coalfields of the Midland basin, in which it occupies a central position, with the other coalfields arranged round it in an almost complete circle. For this reason rocks older than the Carboniferous do not crop out, and have not been encountered in the deepest boring. The Pottery towns lie along a line stretching the length of the central part of the coalfield, and that they are so placed is due to their proximity to the Coal-measure clays and coals essential to the Pottery

trade. Peculiar to itself and to England is the development of the Black Band Ironstones still extensively worked.

On the west, south-west, and south, the Coal-measures sink beneath the Trias, but it is considered that the workable coals lie beyond the depth of 4,000 feet. However, there is within the visible coalfield abundant undeveloped coal and Black Band Ironstones, so that scientifically and commercially the coalfield claims consideration.

The net available quantity of coal remaining unworked is estimated at 4,368,050,347 tons.

The Lower Carboniferous rocks and Millstone Grits rise from beneath the Coal-measures to the north and east of the coalfield. Near the northern end both divisions are at their maximum development in the Midland Province, but the Millstone Grits and the shales and sandstones (Pendleside Series or Limestone Shales) below show a marked attenuation from north to south.

A thin coal rests on the Carboniferous Limestone of Astbury Quarry, and a thin coal is associated with the Millstone Grits. The finer-grained and siliceous varieties of the sandstones in the Limestone Shales and lower parts of the Millstone Grits yield silica rocks much used for silica bricks. The sequence of the Coal-measures is one of great completeness, and, as shown in the following table, attains a thickness of over 7,000 feet at the outcrop, and it is unknown as to what amount of Upper Coal-measures above the Keele Group lies concealed beneath the Trias on the south.

Upper	Keele Beds -	Red and purple sandstones and marls, with Spirorbis limestone; 700 feet. No coals.
	Newcastle-under-Lyme Beds	Grey sandstones and shales, with a Spirorbis limestone at the base; 350 to 400 feet. Thin coals.
	Etruria Marls -	Mottled and chocolate-coloured marls, with fine-grained green sandstone (Espley Rocks); 500 to 1,100 feet. Thin coals.
	Black Band Series -	Grey and black shales, sandstones, and Spirorbis limestones; pottery clays; Bassey Mine Coal at base; 300 to 450 feet. Some coals and Black Band Ironstones.
Middle	Middle Coal-measures -	Grey shales, sandstones, and fireclays; Winpenny Coal at base; 3,000 to 4,000 feet. Important coals. Many Clay-Band ironstones.
Lower	Lower Coal-measures -	Grey sandstones and shales; 1,200 feet. Some coals.

Regarded stratigraphically, the Coal-measures, from the Millstone Grits upwards, may be treated as a whole, since the subdivisions graduate vertically into each other. The selection of a particular coal or Spirorbis limestone as a dividing line is purely arbitrary, and of little stratigraphical significance.

The Lower Coal-measures form a belt of steeply inclined strata on the east and north. Sandstones are developed on a greater scale than in the Middle Coal-measures, but are lenticular and much finer grained than those of the Millstone Grits, except in the north, where a coarse, pebbly sandstone below the Crabtree Coal resembles a Millstone Grit. A grey sandstone, locally red, occurs between the Crabtree and Winpenny coals, and possibly represents the Woodhead Sandstone above the Woodhead Coal of the Cheadle Coalfield. Red shales and grits not infrequently occur between the Crabtree Coal and the Millstone Grit. The commercial value of the seams is small, but the Crabtree Coal, though almost worthless, is interesting, as containing marine shells in its roof shales. It is thus palæontologically as well as stratigraphically comparable with the Mountain Mine Coal of Lancashire. Only a scanty knowledge has been obtained of the flora and fauna.

The Middle Coal-measures contain all the important coals in a belt bordering a central syncline (p. 165) occupied by Upper Coal-measures, where the Bullhurst Coal, practically the lowest seam, lies at a depth of 4,000 feet below OD, but the measures rise again in the west and bring the Bullhurst Coal to an elevation of 900 feet above OD near Apedale Hall. The measures consist essentially of alternations of grey and black shales, grey marls, fireclays, and lenticular masses of sandstone, of which the most persistent bands are those associated with the Cockshead (Eight Feet Bambury), Seven Feet Bambury, and Ten Feet, Winghay, and Great Row coals. The measures as a whole thicken out rapidly in a northerly direction, but diminish very rapidly to the west, the northerly increase taking place chiefly between the Winpenny and Yard coals (List, p. 73), while the westerly attenuation is general. Though grey is the dominant colour of the shales and sandstones of the Ten Feet Rock and Winpenny Rock, the shales about the horizon of the Moss and Yard coals locally assume a red tinge.

Of interest, and peculiar to this coalfield, is the occurrence of a blue limestone containing *Spirorbis* above the Bowling

Alley Coal, which is 2,300 feet below the lowest Spirorbis limestone at the base of the Upper Coal-measures. Thus Spirorbis limestones and red-coloured rocks are not confined to the Upper Coal-measures, and, by themselves, are not safe guides to any position in a sequence of Coal-measures in unproved ground.

With a decreasing value of the coals, the measures above the Ash Coal are rich in bands of argillaceous and carbonaceous ironstone, formerly raised in large quantities; but, and only to a limited extent, the workings are confined to the Burnwood, Gubbin, Chalky Mine, and Cannel Row Half-Yard ironstones. Each of these ironstones is often called a semi-black band. In addition to coal and ironstone, the marls between the Great Row and Bassey Mine coals furnish abundant raw material especially used for sanitary ware and the manufacture of articles essential to the Pottery industry. The marl pits, often of considerable extent and depth, are numerous between Longton and Tunstall.

The palæontological richness of the Middle Coal-measures of the Pottery Coalfield is well known, due in great part to the systematic researches of local geologists, and does not necessarily imply that in this region the conditions were peculiarly favourable to the development of animal and vegetable life and to their preservation.

Below the Ash Coal the commonest plants are *Alethopteris lonchitica*, *Neuropteris heterophylla;* above the Ash Coal *Neuropteris rarinervis* and *Neuropteris scheuchzeri* are common and have not been recorded below this coal. The chief horizons at which plants occur are: a few feet below the Hard Mine Coal, in the roof of the Holly Lane Coal, in the Bowling Alley Rock, in shale over the Ash Coal, over the Great Row Coal, and in the Peacock Marl. Species have a wide vertical range, nor can an assemblage of plants be taken as indicative of a definite horizon, as is claimed for certain of the species and genera of the invertebrata.

The fauna, like the flora, is rich and varied both among the vertebrates and invertebrates. The latter are interesting in revealing many changes from marine to estuarine and back again to marine at several stages during the deposition of the Middle Coal-measures. Of these two faunas, the estuarine shells are of more stratigraphical importance than the marine, since it is claimed that the species of *Carbonicola*, *Anthracomya*, and *Naiadites*, or an assemblage of species, characterize distinct horizons in connection with the chief

seams of coal. The fauna, marine, estuarine, or possibly fresh-water, is distributed in ascending order in relation to the following coals and ironstones: The Cockshead Coal contains *Carbonicola acuta, C. acuta*, var. *rhomboidalis*; roof shales of the Seven Feet Bambury Coal with *Pterinopecten papyraceus, Glyphioceras paucilobum;* Hard Mine Coal with *Anthracomya williamsoni, A. williamsoni*, var. *obtusa ;* Bowling Alley Coal with calcareous shales and limestones; Ten Feet Coal with bed (Mussel band) made up of *Carbonicola acuta ;* Moss Coal with a marine band 30 feet below, and *Carbonicola turgida* in the roof shales; Gin Mine Coal, a marine bed rich in fossils 54 feet below it; Burnwood Coal with *Anthracomya adamsi* and *A. adamsi*, var. *expansa*, in ironstone below. Above the Ash Coal the fish fauna becomes the most prominent feature, especially in association with the ironstone measures; among the shells *Naiadites modiolaris* and *Naiadites quadrata* are common. The latest marine phase occurs at about 600 feet below the Bassey Mine Coal, on an horizon locally known as the 'Bay' or 'Lady' Coal. *Pterinopecten papyraceus*, at one time considered as an exclusively Lower Coal-measure form in Britain, is not uncommon at this high horizon. *Carbonicola robusta*, though not restricted to a single horizon, is most abundant in the lower part of the sequence, and does not ascend above Ten Feet Coal.

Commencing with the Black Band Group, the Upper Coal-measures consist of four distinct lithological types, of which the Black Band Group forms the connecting link with the Middle Coal-measures. Peculiar to the district, the group, as its name implies, is characterized by the presence of Black Band Ironstones, so called from their containing layers of coaly matter. Thin earthy limestones with *Spirorbis* occur at several horizons, and two bands persistently developed near the base contain a minute shell called *Carbonicola vinti*. Such are the distinguishing lithological characters of the group. Its close relationship with the Middle Coal-measures is shown by the identity in character of the beds directly above and below the Bassey Mine Coal, and by the simultaneous gradual increase or decrease in thickness of the two groups as they are traced from south to north or from east to west.

The outcrop of the Black Band Group is easily followed round the central basin by means of numerous marl pits from Longton to Golden Hill, and thence south-west to

Chesterton. It wraps round and delineates the southern end of the western anticline (p. 165). Many of the marl pits are in the clays associated with the ironstones, which are four in number, named in ascending order: Bassey Mine, Red Mine, Red Shagg, and Black Band. Less than 100 feet

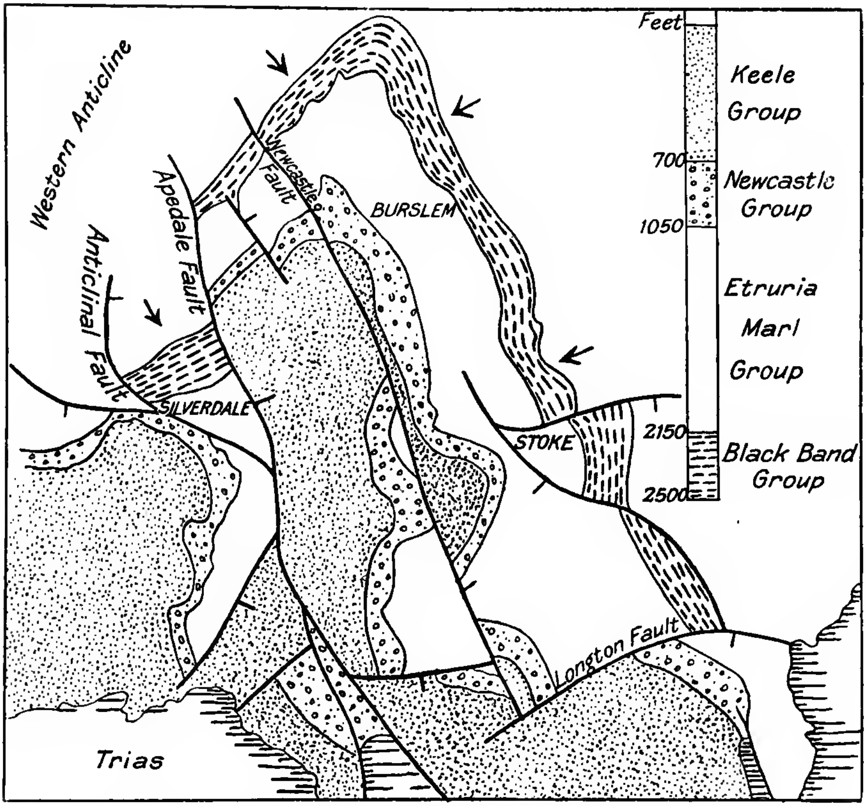


FIG. 30.—SKETCH MAP OF THE UPPER COAL-MEASURES OF THE POTTERIES COALFIELD.

Scale, one inch = 2 miles.

from the base of the Etruria Marl a 'lean' Black Band Ironstone appears in the north and west. The Bassey Mine Ironstone occurs throughout the district, but the others are restricted to an area lying north of the latitude of Stoke-on-Trent. Each ironstone is a laminated, dark brown ore containing numerous *Stigmaria* and countless numbers of the crushed shells of *Anthracomya phillipsi.*

Oil shales, somewhat resembling Torbanite, are associated with the ironstone, and were formerly a source of oil.

Plant remains are abundant throughout the group. Some of the species are rare forms, apparently wanting in the beds below.

The genus *Carbonicola* is represented by *C. vinti* and by *Anthracomya phillipsi*, which is abundant in all the ironstones, thus distinguishing them from the semi-black band ironstones of the Middle Coal-measures, where it is rare or absent. *Spirorbis* is common both in the ironstones and in the limestones, which also contain *Entomostraca* in abundance.

In the succeeding Etruria Marl Group red measures predominate. The salts of iron, to which the red colour is due, are no longer segregated in nodules and bands as in the Black Band Group, but are deposited in pellicles round each grain. Red and mottled marls from 800 to 1,100 feet thick, in which stratification is obscure, are the essential components of the group. At intervals, notably near the base, green and yellow grits, representing the Espley Rocks of South Staffordshire, are developed. Thin bands of Spirorbis limestone with *Entomostraca* occur near the summit and base, and at Chesterton a laminated ironstone with *Anthracomya phillipsi* repeats one of the characteristics of the Black Band Group with which the Etruria Marls are stratigraphically closely allied.

The marls furnish abundant material for bricks, tiles, etc., of excellent quality. Consequently, numerous pits mark the outcrop, which follows that of the Black Band Group.

In the grey sandstones and shales of the Newcastle-under-Lyme Group into which the Etruria Marls graduate upwards there is a return to the grey sediment of the Middle Coal-measures, and a recurrence of the formation of coal, though not to the extent of furnishing workable seams. A constantly developed band of limestone containing *Spirorbis* and *Entomostraca* is taken as the base. The contrast in colour with the red Etruria Marls below and the red Keele Beds above conspicuously indicates the outcrop, and is very noticeable in faulted areas, as around Trentham and Hanchurch.

Plant remains are abundant, and include the first local appearance of *Pecopteris arborescens*, a high zonal species. A small shell named *Anthracomya calcifera* is not uncommon in the basal limestone.

In the Keele Group, Etruria Marl conditions are repeated

as regards coloration, but there is a greater development of arenaceous sediments, and Espley Rocks are absent. The summit of the group is not seen, but at least a thickness of 700 feet is present to the south of Trentham, where red sandstones and crimson marls constitute the highest beds visible beneath the unconformable Bunter Sandstone. Whether conglomeratic sandstones of the Corley and Hunnington types of Warwickshire and South Staffordshire occur beneath the Bunter Sandstone is not known.

Everywhere conformable to the Newcastle-under-Lyme Group, a further connection is shown by the occurrence of Spirorbis limestones at intervals throughout the sequence. Fossils, both plant and animal, are rare, and were practically unrecorded until the material from borings was examined. The list is still meagre, including among the fauna: *Spirorbis, Entomostraca*; and among the flora: *Walchia*, *Pecopteris arborescens*. Remains of the higher vertebrata are not recorded.

The structure, essentially Pennine in character, consists of a central syncline, forming the Pottery Coalfield, enclosed between an eastern and western anticline. Millstone Grits and Lower Carboniferous rocks form the core of the eastern anticline, which trends a little west of north; the western anticline is complicated by faulting, and is composed of segments, each of which, south of Harecastle, is crested with some part of the Middle Coal-measure sequence; north of Harecastle the core is made of Millstone Grits in the south and of Carboniferous Limestone near Astbury in the north.

The eastern anticline, as mentioned, trends west of north; the western anticline, east of north, thus between them enclosing the triangular shaped basin of the Pottery Coalfield. The Potteries syncline is clearly defined by the groups of the Upper Coal-measures in the central parts of the basin, and by the Millstone Grits in the north; but as the measures flatten out south of Stoke-upon-Trent the basin structure becomes obscure.

The composite western anticline is made up of several complete overlapping saddles arranged along a general line of anticlinal folding traversed by faults.

Numerous faults, some of great magnitude, cross the coalfield and, like the folds, radiate outwards from a focus situated in the northern part of the area—that is, they trend north-north-west to south-south-east and north-

north-east to south-south-west. This radial system is crossed by another set of faults trending due east and west, but bending northwards as they approach the radial system.

Few areas are free of faults, and in some they are so numerous as seriously to hamper coal-mining. Of the master faults, that of Apedale is the most conspicuous on account of its linear extension and magnitude of throw. It enters the coalfield to the west of Trentham, and maintains a general north-north-west trend to Apedale, a distance of nine miles. At Spring Wood, north of Apedale, it throws out branches to the north-east and south-west, the main line continuing northwards as the Millstone Fault of Jamage. West of Trentham the fault brings Keele Sandstones on the east against Etruria Marls on the west. At Apedale Ironworks, beds high in the Keele Group are faulted against the Black Band Group, so that its displacement is here between 1,800 and 2,100 feet. On the west or upthrow side of the fault the measures rise up so steeply to the west along the flanks of the western anticline as to bring the Bullhurst Coal to the surface near Apedale Hall at an elevation of 900 feet above OD. On the east or downthrow side of the fault the measures rise up gently to the east, and at the Holditch Pits, a mile east of Apedale, the Bullhurst Coal lies at an estimated depth of over 6,000 feet below OD—a striking example of the profound influence of geological structure on mining.

On the west or Cheshire side of the anticline the Middle Coal-measures plunge down at an angle approaching 90 degrees—the vertical coals being known as 'rearers'—but flatten out on approaching a faulted belt that skirts the outcrop of the Middle Coal-measures along their western margin. The faulted belt consists of faults trending north-east and south-west; their effect is gradually to bring the coals on to the same level as on the upthrow side of the Apedale Fault.

Farther west a fault in the Trias, trending north-east, gradually approaches the coalfield, and north of Harecastle brings the Trias on the west against Lower Coal-measures on the east. In tracing the outcrops of the Coal-measures and Trias north of Audley, this fault brings successively higher strata of the Trias against successively lower strata in the Carboniferous. Owing to the unconformity of the Trias this juxtaposition is not necessarily all due to faulting. The throw of this fault in the Carboniferous rocks is not known.

The most important fault in the synclinal area is the Florence Fault of 750 feet downthrow south, and trending westward from Longton towards Trentham. North of Longton it gives off a northerly fault of 270 feet downthrow south-west, increasing northwards to 750 feet near Etruria.

Of interest, though not affecting the coalfield, is a narrow, nearly vertical dyke of dolerite that runs to the west of, and parallel with, the Apedale Fault to the west and south-west of Trentham. The dyke comes to the surface in Butterton Park, where it is intruded into Keele Beds; farther south in Swynnerton Park it cuts through and alters Keuper Marl.

Coals (lists pp. 72-74).—The seams are numerous, of which no less than thirty-two, with an aggregate thickness of 130 feet, are workable. Bituminous and semi-bituminous classes are represented, producing gas, house, manufacturing, and steam coals. Gas and coking coals occur chiefly in the western anticline, but seams in the Potteries basin also produce coke on suitable treatment. Taking individual seams, the Bullhurst, Cockshead, and Seven Feet Bambury coals are house coals in the east, house or gas coals in the west. The Hard Mine Coal of the east is a good steam and blast-furnace coal; the Ten Feet is a manufacturing coal in the east and a house and gas coal in the west; the Hams and Ragman coals of the west are steam coals; the Moss Coal in the east, and its correlative, the Four Feet Coal, in the west, furnishes a first-class house coal. Cannel is associated with the Moss, Woodmine, and Cannel Row coals, while bastard cannels, somewhat approaching Torbanite in nature, frequently accompany the Black Band Ironstones.

Some of the deepest pits of England are found in the Potteries Coalfield: the shafts of the Shelton Colliery Company have been sunk to the Bullhurst Coal at 3,000 feet depth, and those of the Florence Colliery to the Cockshead at 2,800 feet depth. The majority of the pits are situated on the outcrop of the lower part of the Middle Coal-measures to work the deeper seams; those placed on the higher part do not in most cases extend down to the lower coals. Shafts on the outcrop of the Black Band and Etruria Marl groups are generally carried down to the ironstones and upper seams of the Middle Coal-measures. In the Chesterton area shafts have been sunk through the Keele Beds to win the Red

Mine Ironstone, those of Holditch reaching this ironstone at a depth of 2,140 feet from the surface.

The character of some North Staffordshire coals is shown by the following analyses: Hard Mine—coke, 63·1; volatile matter, 30·2; moisture, 4·5; ash, 2·2. Cockshead—fixed carbon, 64·3; volatile matter, 30·9; sulphur, 0·6; moisture, 1·7; ash, 2·5. Seven Feet Bambury—fixed carbon, 57·44; volatile matter, 37·07; sulphur, 2·09; moisture, 1·28; ash, 2·12. Ash Coal—carbon, 70·04; hydrogen, 5·04; oxygen, 12·02; nitrogen, 1·32; sulphur, 0·28; moisture, 5·49; ash, 5·60.

The future development of the North Staffordshire Coalfield lies within the outcrop of the Upper Coal-measures, where undoubtedly a large quantity of coal ranging from 2,500 to 4,000 feet in depth remains unworked. Except in the extreme south, the Keele Beds, the highest measures at the surface, nowhere exceed 700 feet in thickness, and over much of the outcrop they are under 500 feet thick. A shaft commencing at 500 feet above the base of the Keele Group would reach the Bassey Mine Coal at 1,200 feet depth, and the Great Row and Cannel Row coals at between 2,200 and 2,300 feet depth, the Ash Coal at about 3,000 feet, but the Ten Feet Coal and the best coals will lie at or over 4,000 feet in depth. The great thickness of the barren cover is composed of the Etruria Marls, which are not less than 800 feet thick, and frequently are over 1,000 feet. Except for winning the ironstones and upper coals, areas occupied by the Keele Group will therefore develop later than those districts occupied by the Black Band Series, wherein the lower and better class coals of the Middle Coal-measures occur at depths approaching 3,000 feet.

Cheadle Coalfield.

The north and south anticline of Werrington is succeeded on the east by a downfold enclosing the isolated coalfields of Cheadle, Shaffalong, and Goldsitch Moss, in the form of shallow synclines arranged from south to north. The Cheadle Coalfield alone is of importance and is capable of future development. Circular in shape, with a diameter five miles in length, the area amounts to ten square miles.

The available supply of coal remaining unworked is estimated at 92,577,007 tons.

The Millstone Grits and associated shales ring round the

greater portion of the coalfield, though in places concealed under Trias. Shales, with *Goniatites*, form the lower part of the sequence up to the Third Grit, 150 feet thick, on which rests a coal (Roaches) 2 feet 10 inches in thickness, and formerly much worked. It is overlain by black shales containing *Goniatites*, with shales 100 feet thick between them and the First Grit, which averages 100 feet in thickness.

The Coal-measure sequence given in the following table is incomplete, and probably represents the Lower and Middle Coal-measures below the Burnwood Ironstone of the Potteries, with the Upper Coal-measures certainly absent. As the coalfield lies less than two miles east of the Potteries, the two areas should show a close agreement. This is only partially so, but a strict agreement occurs in the lower part of the sequence.

SEQUENCE IN THE CHEADLE COALFIELD.

	Ft.	*Ins.*		*Ft.*	*Ins.*
Measures	—	—	Measures	6	0
Two Yard Coal	5	6	Foxfield Coal	1	8
Measures	50	0	Measures	60	0
Getley Coal	2	0	Mans Coal	4	6
Measures	20	0	Measures	130	0
Half Yard Coal	2	6	Cobble Coal	2	2
Measures	60	0	Measures, thin coal	150	0
Yard Coal	3	6	Rider Coal	1	6
Measures	50	0	Measures	120	0
Litley Coal	2	9	Woodhead Coal -	2	9
Measures	30	0	Measures, marine bed	450	0
Four Feet Coal	3	6	Sweet or Split Coal	2	9
Measures, three thin coals, main marine bed -	2	0	Measures -	50	0
Dilhorne or Six Feet Coal	6	0	Crabtree or Stinking Coal -	2	0
Measures - -	200	0	Measures	120	0
Alecs or Stinking Coal	3	9	Froghall Ironstone	—	—
			First Grit	10	0

The Crabtree or Stinking Coal is identical in character, and has the same marine shale roof as the Crabtree Coal of the Potteries Coalfield. Above the Crabtree Coal 1,700 feet of measures occur in the Cheadle Coalfield, which agrees with the thickness of the measures between this coal and the Ten Feet Coal in the south-eastern part of the Potteries, but the correlation of individual seams in the two coalfields is uncertain. It is interesting to note that the shales with marine shells between the Dilhorne and Four Feet coals approximate

in position with the marine band above the Seven Feet Bambury Coal of the Potteries, so that the Dilhorne Coal is the possible equivalent of the Eight Feet Bambury or Cockshead Coal.

The structure of the coalfield is that of a basin with the more steeply inclined strata in the west. Numerous faults cross the area trending north and south, and intersected by an east and west set of faults. The most important is the east and west fault at Dilhorne, with a throw of 120 feet to the south, introducing an area of Dilhorne Coal. A fault trending north-west and south-east of improved throw in the Carboniferous rocks traverses the Trias south of Dilhorne.

The chief coals are the Woodhead, Dilhorne, Four Feet, and Yard coals. The Half Yard Coal is only of fair quality. Workable ironstones, except that of the Froghall Hæmatite, are absent, and though there is some doubt as to the highest measures reached in the Cheadle Coalfield, the sequence does not extend up to the Burnwood Ironstone of the Potteries, and certainly nowhere approaches the horizon of the Black Band Ironstone Group.

Fossils, both plant and animal, are abundant. The fauna, 71 feet below the Four Feet Coal at Draycott Colliery, includes: *Lingula mytiloides*, *Productus scabriculus*, *Posidoniella sulcata*, *Pterinopecten papyraceus*, *Pt. carbonarius*, *Leiopteria longirostris*, *Dimorphoceras gilbertsoni*, *Glyphioceras bilingue*, *Pleuronautilus pulcher*. Fish remains are common in the roof shales of the Cobble and Woodhead coals. *Anthracomya williamsoni* is associated with the Litley and Half Yard coals; *Carbonicola robusta* occurs in measures between the Cobble and Dilhorne coals.

Shaffalong Coalfield.—The anticline bordering the Potteries Coalfield on the east is succeeded by a narrow syncline, four miles in length, and less than a mile broad, occupied by Lower Coal-measures. Only the Crabtree Coal is present, and the measures above do not extend as high as the Woodhead Coal of the Cheadle Coalfield, less than a mile east of the southern end of the fold. Near its margins the measures approach verticality, but flatten out rapidly towards the centre of the basin. They are commercially worthless as regards coal, and, in spite of statements to the contrary, ironstone in remunerative quantities does not exist.

Goldsitch Moss Coalfield.—Surrounded in perfect symmetry by the First and Third Grits, this small basin, comparable in size to that of Shaffalong, lies ten miles east of Congleton. The Feather Edge Coal, 4 to 6 feet thick, and correlative with the Crabtree Coal, is overlain by 550 feet of measures containing five seams of coal from 1 to 2 feet in thickness.

CHAPTER XIII

YORKS, NOTTS, AND DERBY COALFIELDS

It is a common practice to speak of the coal-producing areas in Yorkshire, Nottinghamshire, and Derbyshire as if each county had its own special type of coalfield. This is not the case ; geologically, the three coal regions form a unit and, commercially, the same classes of coals occur throughout. The three regions occupy a one and indivisible basin possessing a common geological structure and sequence, but showing many characteristics distinguishing it from the other members of the Midland Province. It is, perhaps, more closely allied to the coalfields of Lancashire and North Staffordshire, on the west side of the Pennine axis, than with those of South Staffordshire, Warwickshire, and Leicestershire on the south of the central Pennine uplift of Lower Carboniferous rocks. One seam of coal near the base of the Lower Coal-measures is identified in the east and west, and probably some of the coals in the Middle Coal-measures of the East Midland and Yorkshire Coalfields were once continuous with those of Lancashire; moreover, the Lower Coal-measure sequence of Nottinghamshire closely approximates that of North Staffordshire.

In its commercial aspect the East Midland Coalfield consists of a 'visible' coalfield in the west and a 'concealed' coalfield in the east. The combined area is roughly oval in shape, amounting to 2,136 square miles, or roughly twice the size of the South Wales Coalfield. The length of the proved coalfield lies between the Humber at Selby in the north and eight miles south of Nottingham in the south, a distance of sixty-eight miles. Its greatest width, on the latitude of Sheffield, is about forty miles. The navigable Trent skirts the western margin, and the Aire and Don rivers traverse the northern area. A large part of the coalfield has therefore a water access to the sea. The chief manufacturing towns in the area are connected by an intricate railway system penetrating the visible coal-

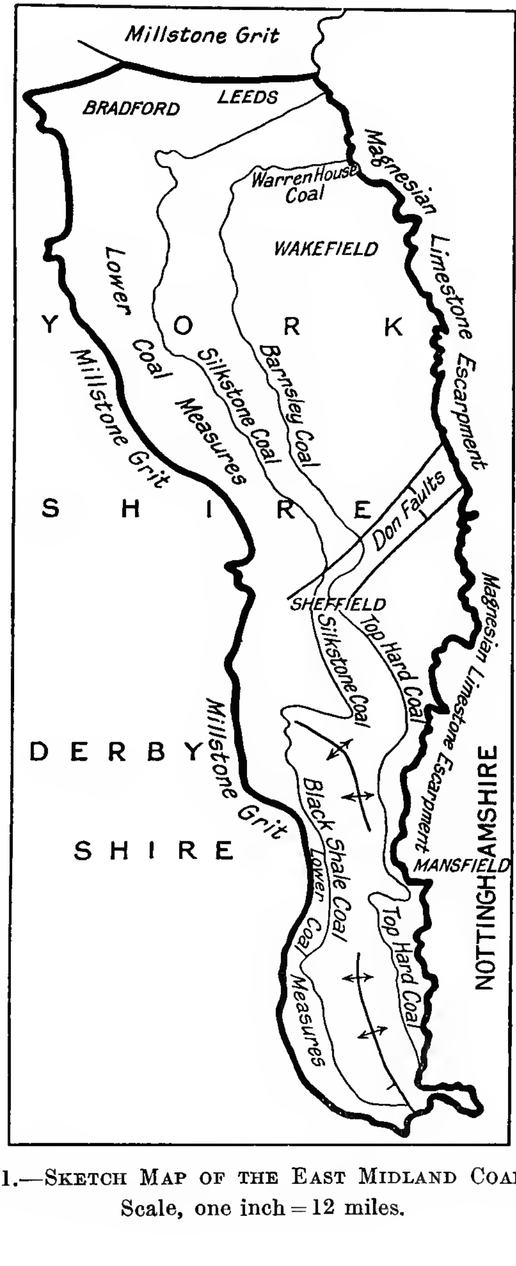


FIG. 31.—SKETCH MAP OF THE EAST MIDLAND COALFIELD.
Scale, one inch = 12 miles.

field in all directions. Physiographically the region includes bleak moorland in the west, uplands in the centre, and broad lowlands and alluvial flats in the east.

For the whole area the net available supply of coal is estimated at 26,498,731,495 tons.

The Lower Carboniferous rocks, consisting of the Carboniferous Limestone, Limestone Shales (Yoredale Rocks, Pendleside Series), crop out in the west, and were penetrated in a boring at Kelham near Newark. The periclinal mass of Carboniferous Limestone, over 2,000 feet thick, occupies the core of the Pennine anticline in Derbyshire, and throws off to the east successively the Limestone Shales, Millstone Grits, and Coal-measures. Though without coals, the limestone has recently been proved, in borings near Chesterfield, to yield oil, but so far it is not known if it occurs in commercial quantities. It also furnishes an unlimited supply of flux for the blast furnaces and the well-known ornamental marbles and building stone of Hopton Wood and Middleton.

Thin films of coal are occasionally found lying on or a few inches above the limestone. Galena, cerussite, zinc blende, calamine, barytes, and calcspar occur in veins and pockets.

The Limestone Shales consist of shales and thin bands of earthy limestone containing *Martinia glabra*, and also *Pterinopecten papyraceus*, *Glyphioceras phillipsi*, two fossils recurring at several horizons in the Middle Coal-measures. Direct measurements of thickness are not obtainable, but the group is considered to maintain an average thickness of about 400 feet. The occurrence of thin and impersistent seams of coal from one-quarter to an inch thick are of interest, since they show the commencement of conditions favourable to the formation of coal.

Stratigraphically, no break has been detected between the Limestone Shales and Millstone Grits, or between these and the Coal-measures, the succession of rock types being arranged in the following unbroken sequence:

Upper Coal-measures (in borings only)	Keele Beds	Red and purple marls and sandstones (of Thurgarton); 200 feet.
	Newcastle - under - Lyme Group	Grey sandstones and shales; thin coals; 100 feet.
	Etruria Marls	Red and mottled marls with green grits (Espley Rocks); 300 feet.

Middle Coal-measures	Middle Coal-measures	Grey sandstones, clays, and shales; numerous coals; clay, ironstones, Silkstone, or Black Shale Coal at base; 2,000 to 3,000 feet.
Lower Coal-Measures.	Lower Coal-measures	Grey sandstones, shales, ironstones, and workable coals in north and south; base First Millstone Grit; 1,100 to 1,650 feet.
Millstone Grit Series	Millstone Grits	Massive sandstones and grits; shales and some coals; 1,100 to 1,650 feet.

In descending order the chief bands of the Millstone Grits are: Rough Rock or First Grit (80 to 100 feet); Longshaw Grit (0 to 30 feet); Chatsworth or Rivelin-Belper Grit (100 to 250 feet); Kinderscout Grit in two beds separated by shale (250 to 500 feet); Shale Grit Group, mainly shales (100 to 350 feet). Shales with ganister-like rocks and fireclays with or without coals (50 to 100 feet) separate the various grits, which vary greatly in texture and coarseness. Among the shales it is noticeable that marine bands increase in number northwards, where they are occasionally found in the condition of earthy limestones. Coals from 3 feet to 3 feet 6 inches in thickness are associated with the grits, that above the Kinderscout occasionally reaching a thickness of 4 feet of coal with a shale parting from 6 to 12 inches thick.

The fossil flora is imperfectly known; the fauna, which is confined to the shales, is noticeable for the occurrence of the marine shells *Lingula mytiloides*, *Posidoniella lævis*, *Pterinopecten papyraceus*, *Glyphioceras bilingue*, and for the appearance of the goniatite genus *Gastrioceras*. *Carbonicola*, *Anthracomya*, and *Naiadites* are not recorded.

While the general sequence remains constant on the whole, considerable variations in thickness take place in the individual grits, and the sum of the maximum thickness of the different members is in excess of the thickness of the whole series in any one place. It may amount in some places to 1,400 or more feet, and in others seems to have temporarily lost much of this amount, as in the Kelham Boring, near Newark, where the full thickness, unless partly faulted out, is only 200 feet.

Along the southern margin of the coalfield the series, except the First Grit, is hidden under Trias, but at Ruddington Boring, four miles south of Nottingham, a thickness of

1,000 feet was proved, including 109 feet of Kinderscout Grit, in which the boring ended. The Kelham Boring and those of the oil wells east of Chesterfield are the only explorations penetrating through the horizon of the Millstone Grits at spots removed some distance from the outcrop.

With the Lower Coal-measures the formation of more or less persistent beds of coal commences, but they are more locally distributed than the seams of the Middle Coal-measures. In descending order the chief seams are: Silkstone (Blocking or Barcelona Coal), Whinmoor and Beeston coals, Grenoside Sandstone Coal, Crow Coal, Black Bed Coal, Underclay or Thin Coal, Better Bed Coal, Alton, Ganister or Hard Bed Coal, Coking or Soft Coal.

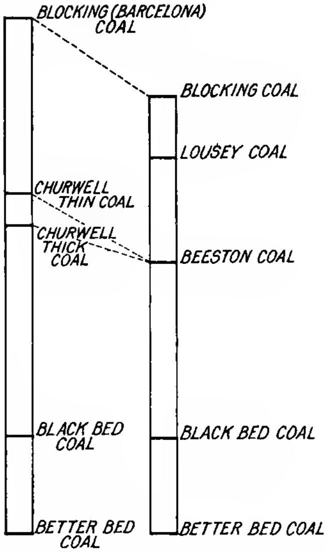


FIG. 32.—TO ILLUSTRATE THE SEQUENCE BETWEEN THE BETTER BED COAL AND THE BLOCKINC COAL.

Scale, one inch = 200 feet.

In describing the Coal-measures, owing to their unequal development, it is convenient to keep the concealed areas distinct from the visible.

At the southern end of the coalfield the Lower Coal-measures are about 1,000 feet thick, thence gradually expanding northwards to 1,650 feet in South Yorkshire; they are reduced to about 1,000 feet thick in the northern part of the coal-field. The expansion is due to the incoming of sandstones in the upper part of the sequence. In the south the sandstones are generally soft and impersistent; but at their maximum development in the Sheffield district they become coarse and sometimes conglomerate rocks indistinguishable from Millstone Grits, and, like these, form bold features, as in the well-known Wharncliffe Crags.

The sandstones furnish building stones and silica rocks in the lower portion of the sequence. A thin bed of hard silt, from 1 to 6 feet thick, occurring beneath the Alton or Hard Bed Coal, forms the well-known Sheffield ganister. The clays associated with the coals are the sources of raw

material for making firebricks, sanitary ware, and coarse pottery on an extensive scale in the Leeds, Halifax, Huddersfield, and Sheffield districts.

Of the coals, the Alton of Derbyshire and its equivalent the Ganister (Halifax or Hard Bed) of Yorkshire can be recognized as a seam persisting over the whole visible coalfield, and has also proved in borings at Ruddington and Kelham. It is recognized by the marine bed above it. Of only poor quality in Derbyshire, it is extensively mined in Yorkshire between Sheffield and Huddersfield and around Halifax, but mainly in connection with the ganister and associated fireclays. Above the Alton, the Kilburn Coal is famous as a house coal, but thins out north of Alfreton and is not recognizable in Yorkshire. Formerly much clay-ironstone was obtained from measures below the Kilburn Coal; but ironstones are scarcer in the Lower Coal-measures of Yorkshire. North of Huddersfield the Better Bed Coal, of great purity, and therefore pre-eminently suitable for iron smelting, is an important seam around Bradford, Leeds and Wakefield. It is not recognizable south of Barnsley.

An analysis of the Hards of the Better Bed Coal gives: Carbon, 83·45; hydrogen, 5·38; oxygen and nitrogen, 7·63; sulphur, 0·41; ash, 1·08; water, 2·08; and of the Soft Coal: Carbon, 84·03; hydrogen, 4·08; oxygen and nitrogen, 7·11; sulphur, 0·41; ash, 1·75; water, 1·72.

Around Leeds, Garforth, Marston, and Peckfield, the Beeston Coal, occasionally 8 feet thick, is one of the most valuable seams in the northern part of the district, but has no value, if indeed it occurs of a workable thickness, over the rest of the coalfield. It is thus seen that the coals of the Lower Coal-measures reach importance only locally in the visible coalfield. In the concealed area, so far as a few borings give the necessary information, they do not yield seams of commercial value.

Little is known of the flora of the Lower Coal-measures. Below the Kilburn Coal only seven species have been recorded. Above this coal the list contains twenty-nine species, all of which, except *Sigillaria discophora* and *Rhabdocarpus elongatus*, occur above the Silkstone Coal, and one, *Alethopteris serli*, is more abundant in the lower part of the Upper Coal-measures of other coalfields.

The chief beds yielding animal remains are the roof shales of the Alton or Ganister Coal, the roof shales of the Kilburn Coal, and the ironstones below it. The shales

above the Alton or Ganister Coal yield a fauna characteristic of the Crabtree Coal of North Staffordshire (p. 160) and the Mountain Mines of Lancashire. Fish remains are the chief fossils associated with the Kilburn Coal; species of *Anthracomya*, *Carbonicola*, and *Naiadites* occur sparsely throughout the measures.

The outcrop of the Lower Coal-measures follows that of the Millstone Grits generally as a natural boundary, but faulted in places along the northern and southern margins. In the concealed areas their margins can be estimated only in the south-west of Nottinghamshire by the Ruddington Boring and south of Newark by the Kelham Boring.

In the Middle Coal-measures the seams of coal are at their maximum development as regards thickness, quality, and persistence of individual seams. On the other hand, the associated measures are more variable than those of the Lower Coal-measures—sandstones and shales alternating in an irregular manner. Individual beds of sandstone are most persistently developed, and are at their maximum development over the central part of the coalfield, but even here are localized and either wedge out rapidly or, by the intercalation of shale, lose their character and cease to be recognizable as individual beds.

These varying sediments were considered to have been deposited under estuarine conditions; but, if so, the occurrence at several horizons of beds with a marine fauna—three of which, at least, extend over the whole area—indicates extensive and probably prolonged incursions, of the Carboniferous sea. The remarkable persistence of these marine bands in the roof shales of some of the coals suggests deposition under lagoon conditions rather than under the eddying waters of an estuary.

The Middle Coal-measures, like the Lower Coal-measures, show an area of maximum deposition with its centre about the latitude of Sheffield, where they attain a thickness of over 3,000 feet; to the north and south this is reduced to about 2,000 feet. This variation is not distributed over the sequence as a whole, but the increase of about 1,000 feet takes place in the measures above the seam known as the Top Hard Coal in Derbyshire and as the Barnsley Coal in Yorkshire. Below this coal the measures maintain a nearly uniform thickness.

The Barnsley or Top Hard Coal is by far the most important seam of coal, and is practically the only coal at present worked to any extent in the concealed coalfield.

For this reason it is convenient to consider the sequence in relation to this coal.

In Yorkshire the descending and correlative sequence of coals below the Barnsley is: Swallow Wood, Netherton Two coals, Haig Moor; Joan, Mitchell, or Parson's Coal; Heward, Flockton Thick, and Adwalton Stone Coal; Flockton Thin, Adwalton Black Bed Coal; Middleton High Main or Forty Yards Coal; Fenton's Coal; Parkgate, Old Hard, Two Yards,

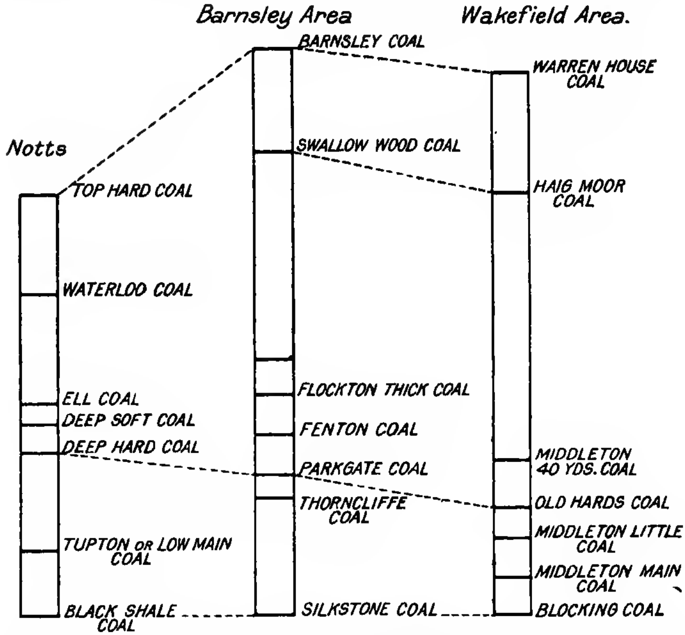


FIG. 33.—VERTICAL SECTIONS (SILKSTONE TO TOP HARD) OF THE YORKS-NOTTS COALFIELD.
Scale, one inch = 400 feet.

Brown Metal, and Firthfield Coal; Walker's or Thorncliffe Thin, Green Lane, Middleton Little, Hard Band coals; Swilley New Hards, and Middleton Main Coal; Silkstone, Four Feet, Wheatley Lime, Three-Quarters, and Middleton Eleven Yards.

The corresponding important seams of Derbyshire and Nottinghamshire are illustrated by the vertical sections (Fig. 33).

The most prominent sandstones are those associated with the Silkstone and Deep Hard or Parkgate coals. Below the Waterloo coals in Derbyshire and Haig Moor Coal in Yorkshire dark-coloured shales with *Carbonicola* and

ironstones are frequent. Above these coals intercalations of grey sandstones amidst sandy grey shales characterize the sequence.

The more important coals are the Silkstone, Middleton Main, Tupton or Low Main, Deep Hard (Derbyshire) or Parkgate (Yorkshire), Deep Soft (Derbyshire) or Flockton (Yorkshire), and Haig Moor (Yorkshire) coals, all of which are extensively worked. These include coking, gas, house, manufacturing, and steam coals. The Silkstone is the chief gas and coking coal, and is also well known as a house coal; the Parkgate or Deep Hard furnishes coking, gas, manufacturing, and steam coal. Cannel, in lenticles and wedges, is associated with many of the seams, notably the Silkstone and Tupton or Low Main. The Silkstone Coal is at its best over the central region, but by the introduction of dirt partings deteriorates to the north and south.

The following analysis gives the composition of the Tupton (Low Main) Coal: Carbon, 67·93; hydrogen, 4·45; oxygen, 10·16; nitrogen, 1·22; sulphur, 0·62; ash, 3·84; water, 11·58.

The subgroup of the Middle Coal-measures below the Barnsley and Top Hard Coal occupies a wide outcrop in Derbyshire and Yorkshire parallel with that of the Lower Coal-measures, and is an important source of coal in Derbyshire and Yorkshire; but in Nottinghamshire the outcrop is limited. The seams, however, are worked beneath the Permian rocks, and have been proved to be intact and of equal quality under the Trias of the Ollerton district. The subgroup also furnishes the seams worked south of the Trent under the Trias of Clifton.

The Top Hard or Barnsley Coal is not only the most important seam in the coalfield, but exists as a practically undivided bed over an area of 600 square miles at least. 'Washouts' occur, but are not numerous. The seam, though locally slightly under 3 feet thick, is sometimes as much as 11 feet, and maintains an average of 5 feet of coal over wide areas. Characteristic of the seam is a band of dull coal, termed the 'Hards,' from 1 to 4 feet thick, developed at or near the base, and furnishing a high-class steam coal. This part of the seam is shipped in large quantities from the Humber and East Coast ports, and it may be truly said that the modern developments of the concealed areas have depended on its presence. At Hemsworth a shale parting appears in the Barnsley Coal, and at Wakefield several such layers occur, until northwards the seam becomes worthless and is known as the 'Gawthorpe'

Coal.' At the south end of the coalfield, at Clifton Colliery, the seam, 6 feet thick, is undivided, and how far it extends in this condition to the east and perhaps to the south-east

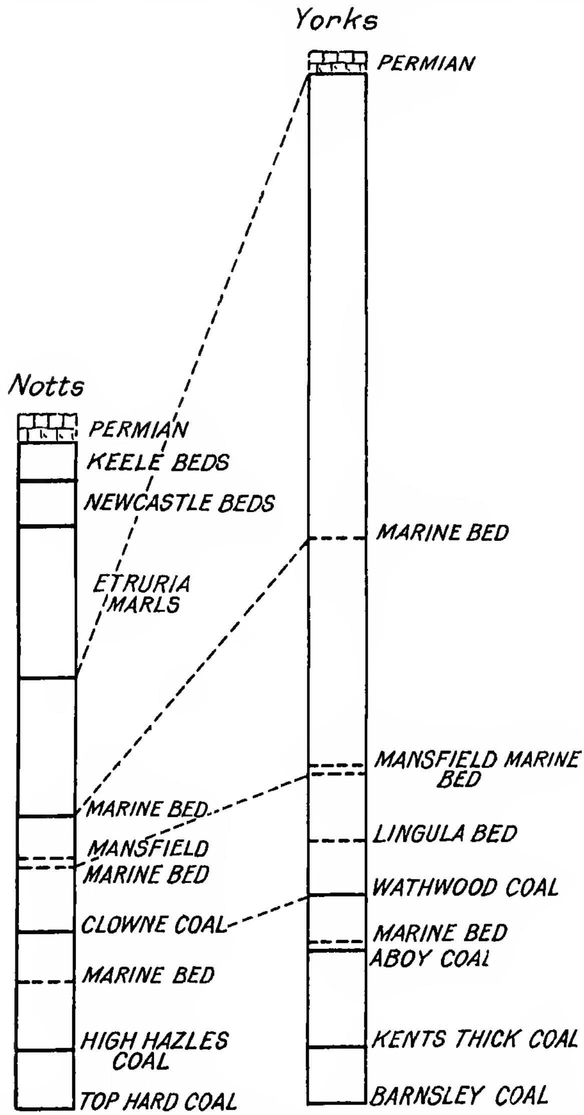


FIG. 34.—VERTICAL SECTIONS (ABOVE TOP HARD) OF THE YORKS-NOTTS COALFIELD.

Scale, one inch = 500 feet.

is unknown. Though not absolutely proved, it appears that the seam terminates short of the Trent between Newark and the Humber. In the Doncaster district and north-east of Doncaster the Barnsley Coal is sometimes over 10 feet thick. A typical section of the Top Hard Coal shows: Soft coal, 1 foot; rifler coal, 1 foot; best hard, 2 feet; soft coal, 1 foot 6 inches. A section of the Barnsley Coal gives: Soft coal, 1 foot 6 inches; hards, 4 feet 6 inches; soft coal, 1 foot 6 inches. The roof is generally a sandy shale with plants, less frequently a sandstone.

Analyses give: Barnsley Hards (Cadeby): Carbon, 77·39; hydrogen, 4·81; oxygen, 9·14; nitrogen, 1·59; sulphur, 0·59; ash, 3·64; moisture, 2·84. Top Hard, Brights: Carbon, 72·44; hydrogen, 5·26; oxygen, 7·80; nitrogen, 1·71; sulphur, 1·21; ash, 2·08; water, 9·50. Top Hard, Hards: Carbon, 76·10; hydrogen, 5·11; oxygen, 5·84; nitrogen, 1·58; sulphur, 0·86; ash, 2·38; water, 8·13.

The strata above the Top Hard or Barnsley Coal consist of grey sandy shales, grey shales, and lenticular beds of grey sandstone. Over the central area, extending from Pontefract on the north to Retford on the south, the occurrence of sandstone in more or less definite beds is a prominent feature. These sandstones are locally red, and with them are associated red shales. The order of the coals and sandstones is given below:

Nottinghamshire.	*Thickness in Feet.*	Yorkshire.	*Thickness in Feet.*
		Measures	
		Measures	
		Wickersley, Houghton Common, or Pontefract Rock	
		Measures	
		Dalton, Brierly, or Ackworth Rock	
Measures with thin, unnamed, and impersistent coals; no definite beds of sandstone	700	Measures with Great Houghton and Thryberg Rock	
		Shafton, Nostel, Billingley, and Denaby coals	1,300 to 1,600
		Upper Chevet Rock and equivalent measures	
		Measures with Middle and Lower Chevet Rock and Sharlston and Crofton Coals	
		Treeton or Oaks Rock and associated measures	

MANSFIELD MARINE BED.

	Thickness in Feet.		*Thickness in Feet.*
		Measures with Swinton Pottery, Newhill or Steam coals -	
		Wooley Edge Rock or equivalent measures	300
Clowne Coal (?) -	150	Aston Common, Wathwood, Meltonfield, Woodmoor or Wakefield Muck Coal	
		Measures - -	
		Foxearth, Two Feet, Half Yard, Riding or Cat Coal	
Measures with thin coals -	300	Measures -	
		Sough or Yard, Abdy, Winter or Stanley Scale Coal	
		Measures	350 to 400
		Furnace, Beamshaw, Stanley Main Coal -	
		Measures with Kents Thin Rock -	
		Kents Thin Coal -	
High Hazles Coal -		Measures with Kents Thick Rock -	
		Kents Thick or Mapplewell Coal -	
Measures with Top Hard Rock -	150-200	Measures with Barnsley Rock -	150 to 250
Coombe Coal (?) -		Barnsley Rider Coal	
Top Hard Coal - -		Barnsley, Warren House or Gawthorpe Coal -	

In Nottingham the outcrop is narrow, and rarely gives more than the lower part of the sequence; in Derbyshire also the highest beds are not exposed; but in Yorkshire, in the Rotherham district, where also the sandstones are well developed, the sequence extends up to the base of the Upper Coal-measures in the Brick Pits at Conisborough.

In borings in Nottinghamshire the measures between the Top Hard and Upper Coal-measures are 1,300 feet thick, and at Maltby Colliery in Yorkshire 2,260 feet. It will be noticed that the increased thickness is chiefly in the measures above the Mansfield Marine Bed. Red sandstones, often caused by the leaching out of iron oxides from hæmatite nodules enclosed in the sandstones, are locally met with in the Treeton, Wickersley, and Ackworth rocks of Yorkshire, at the outcrop around Rotherham; in shafts and borings

at Shireoaks, Firbeck (Wallingswell), South Carr (Haxey), Maltby; in Nottingham at Manton Colliery. Formerly all

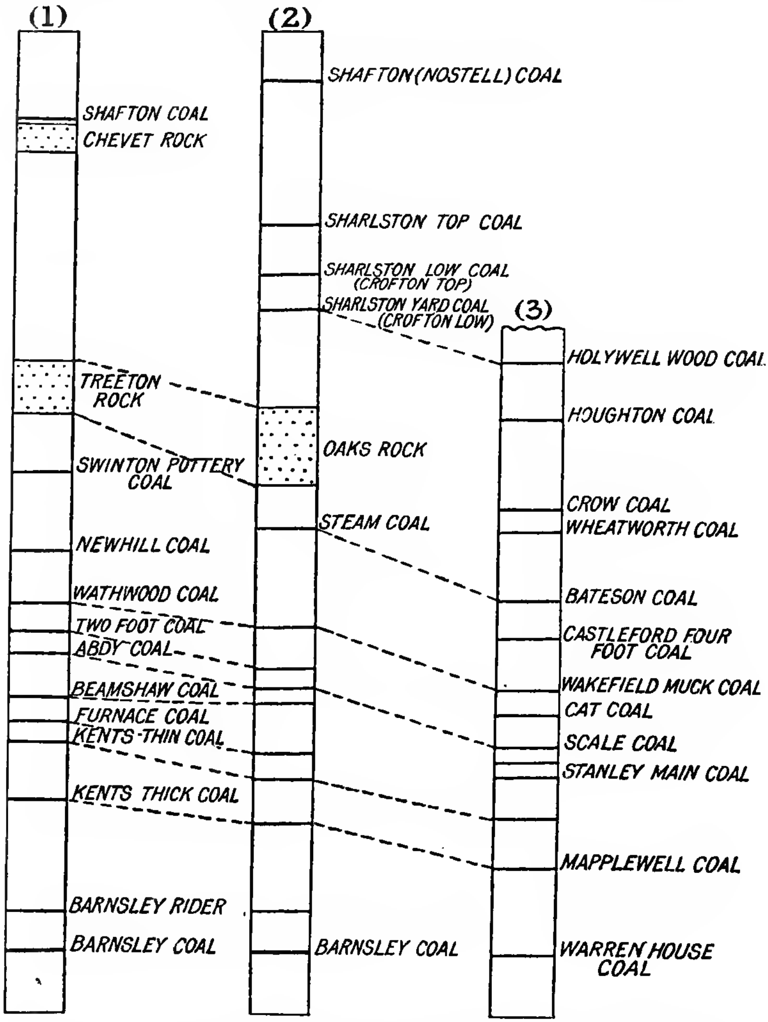


Fig. 35.—Vertical Sections of the Yorkshire Coalfields, Sheffield (1), Barnsley (2), and Wakefield (3) Districts. Scale, one inch = 400 feet.

red Coal-measure sandstones above the Barnsley Coal were identified as one bed (Red Rock of Rotherham), and an unconformity deduced from these red sandstones occurring at very different distances above the Barnsley Coal.

The coals above the Barnsley and Top Hard are not extensively worked, and are practically confined to the Kents Thick (High Hazles), Stanley Main, Wathwood, Sharlston, and Shafton coals.

The High Hazles shows a composition of: Carbon, 79·04; hydrogen, 5·75; nitrogen, 0·98; oxygen, 11·77; sulphur, 1·06; ash, 1·40.

Particular attention is drawn in the table (p. 183) to the Mansfield Marine Bed on account of its unique character and rich marine fauna. It consists of from 10 to 30 feet of blue shales resting on a dark blue earthy limestone 1 to 3 feet thick, and this in turn on a thin coal. It is persistent throughout the coalfield, varying from 430 feet above the Top Hard Coal in the Bilsthorpe Boring to 730 feet at Maltby Colliery, thus showing a slight attenuation of the measures from north-west to south-east. The earthy limestones and shales repeat the characters of the Limestone Shales, and this is further accentuated by the fossils, which are all of marine species and include the following forms:

Spirorbis sp.
Chonetes laguessiana (*de Kon.*).
Lingula mytiloides (*J. Sow.*).
Orbiculoidea nitida (*Phill.*).
Productus anthrax (*Hind*).
Rhipidomella, *cf.* michelini (*Leveillé*).
Rhynchonellid.
Spiriferina.
Allorisma, sp. nov.
Aviculopecten culpini (*Hind*).
Aviculopecten, sp. nov.
Ctenodonta lævirostris (*Portl.*).
Ctenodonta undulata (*Phill.*).
Edmondia sp.
Myalina compressa (*Hind*).
Nucula æqualis (*J. de C. Sow.*).
Nucula gibbosa (*Flem.*).
Nucula luciniformis (*Phill.*).
Nuculana acuta (*J. de C. Sow.*).
Nuculana, *cf.* acuta.
Nuculana attenuata (*Flem.*).
Posidoniella lævis (*Brown*).
Posidoniella sulcata (*Hind*).
Pseudamusium anisotum (*Phill.*).
Pseudamusium fibrillosum (*Salt.*).
Pterinopecten carbonarius (*Hind*).
Pterinopecten papyraceus (*J. Sow.*).
Sanguinolites, sp. nov.
Scaldia carbonaria (*Hind*).
Schizodus antiquus (*Hind*).
Solenomya primæva (*Phill.*).
Syncyclonema carboniferum (*Hind*).
Bellerophon sp.
Euphemus d'orbignyi (*Portl.*).
Euphemus, *cf.* urei (*Flem.*).
Loxonema acutum (*de Kon.*).
Loxonema ashtonense (*H. Bolton*).
Trepospira radians (*de Kon.*).
Cœlonautilus sp.
Dimorphoceras gilbertsoni (*Phill.*).
Ephippioceras clitellarium (*J. de C. Sow.*).
Gastrioceras carbonarium.
Glyphioceras, *cf.* micronotum (*Phill.*).
Glyphioceras phillipsi (?) (*Foord and Crick*).
Glyphioceras paucilobum (*Phill.*).
Glyphioceras reticulatum (*Phill.*).
Orthoceras asciculare (*Brown*).
Orthoceras koninckianum (*d'Orb.*).
Orthoceras steinhaueri (*J. Sow.*).
Pleuronautilus costatus (*Hind*).
Pleuronautilus, *cf.* pulcher (*Crick*).
Solenocheilus sp.
Temnocheilus carbonarius (*Foord*).

The flora of the Middle Coal-measures is rich in species and genera of Filicales, Pteridosperms, Equisitales, Sphenophyllates, and Lycopodales.

In the fauna the more interesting are the marine shells, which occur above the Ell Coal, above the Abdy Coal, in the Mansfield Marine Bed, and in a bed 300 feet above it. No bed approaches in richness the Mansfield Marine Bed, which includes all the known marine forms of the Coal-measures. Moysey records, from measures between the Waterloo and Top Hard coals, *Crustacea*, some rare *Eurypterids*, *Myriapods*, and *Arachnids*. Species of *Anthracomya*, *Carbonicola*, and *Naiadites* are common between the Silkstone and the Top Hard coals, and gradually die out above the Mansfield Marine Bed. *Anthracomya phillipsi* does not range below the Top Hard, and *Carbonicola robusta* does not ascend above the Deep Hard Coal.

The elongated basin-fold containing the Coal-measures of the East Midland Coalfield has its western margin completely exposed; a part only of the northern and southern margins is at the surface, while the whole of its eastern margin lies concealed under the Permian and Trias rocks that extend in the north and south across the upturned edges of Carboniferous rocks and eastward over the central axis of the fold. Thus the main framework of the basin is out of sight; but its composition can to some extent be made out from information obtainable at the surface in the visible coalfield, combined with that revealed by shafts and borings penetrating into the concealed Carboniferous rocks under the Permian and Triassic formations.

The Magnesian Limestone, striking north and south, is at right angles to the direction of strike of the northern exposed margin of Coal-measures, while on the south the Trias, inclined south, rests on Carboniferous rocks dipping north; moreover, though some structures are common to the older and newer formations, several of a pronounced type seen in the Coal-measures have no effect on the Magnesian Limestone outcrop as it sweeps down the length of the coalfield; neither are the conspicuous variations observed in the strike of the Coal-measures reflected in the overlying formations. It is obvious, therefore, that the structures discernible in the outcropping Permian and Trias do not afford a key to those in the buried Coal-measures. So marked is the discordance between the older and newer formations that it was thought for a long time that the coalfield terminates

at the outcrop of the Magnesian Limestone, and the sinking of the Shireoaks Pits in 1854 was regarded as a bold speculation, though William Smith in the early part of last century regarded the Coal-measures as extending a long distance beneath the Permian.

In the visible coalfield the Coal-measures along the entire outcrop in the west dip east, conforming to the dip of the Millstone Grits. The irregular outline of the outcropping Coal-measures is due to denudation, except along the northern boundary, where for some distance west of the Magnesian Limestone escarpment the outcrop coincides with a fault trending east and west, with a downthrow south. Several faults in the Millstone Grit country to the north trend north-east and south-west in the direction of the Harrogate anticlinal that brings up the Lower Carboniferous rocks. The exposed southern edge of the coalfield is also for the most part an east and west fault, bringing Trias, dipping south, against Coal-measures inclined north. The northern faulting does not break through the Magnesian Limestone escarpment, but the east and west southern faulting extends into and affects the Trias.

The main structures within the coalfield are connected with the Pontefract faults, the Don Valley system of faulting, and the faulted Brimington and Erewash anticlinal uplifts. These disturbances trend east of north or south of east. The Pontefract and Don faults displace slightly the Magnesian Limestone; but, on the contrary, the Brimington disturbance passes beneath undisturbed Permian strata.

Between the Don faults the Coal-measures range in a north-easterly and south-westerly direction, with a dip to the south-east; in the adjoining country on either side of the faults, the strike is north-west and south-east, with a dip to the north-east. No change in the direction of strike is observable in the overlying Trias. The Barlow Boring, near Selby, and the shafts of Hatfield Colliery, north-east of Doncaster, are situated on a prolongation of two systems of faults under the Permian; and it is significant that both the Barlow and Hatfield borings have been sunk on faults. Borings near Armthorpe also suggest the vicinity of the Don system of faulting; but the shafts of Brodsworth, Bentley, Bullcroft, and Thorne collieries lie in a belt between the Pontefract and Don faults.

The Brimington anticlinal disturbance enters the coalfield at Holmesfield as an east and west fold. It gradually

bends to the south, and at Brimington it is directed due south; up to this point it is a sharp fold with Lower Coal-measures along the crest. South of Brimington the fold passes into a fault system, which gradually turns to the east and then passes under the undisturbed Magnesian Limestone near Skegby. The continuation of the line of this fault system under the Permian and Trias would pass about one mile south of a line between Mansfield and Newark. That the fault continues is shown by borings near Kelham and Southwell, which entered a fault accompanied in each case by a dolerite intrusion and an outflow of oil in the Millstone Grits at Kelham. Borings also at Farnsfield and Allesford Lane penetrate Upper Coal-measures beneath the Permian so that the Top Hard Coal lies several hundred feet lower than is calculable on the dip and strike proved at Rufford Colliery to the north of Farnsfield.

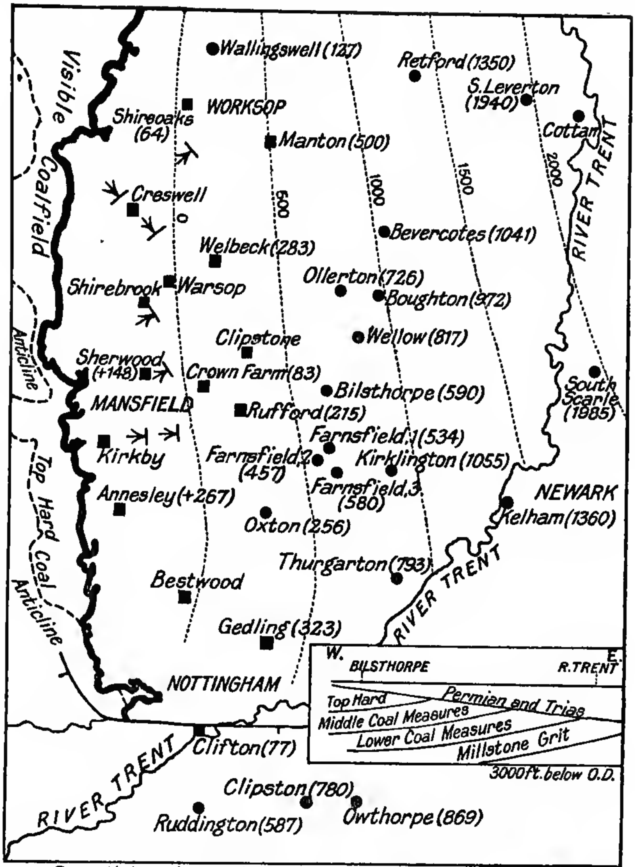
The Erewash Valley anticline appears as a gentle dome in the Coal-measures south-east of Alfreton, and brings Lower Coal-measures to or near the surface near Codnor Park. It trends north-north-west and south-south-east, and is accompanied by a fault having the same direction, which continues to the southern margin of the coalfield, where it joins the east and west, Clifton faults. In the Coal-measures at Clifton Colliery, south of Nottingham, one of these faults, with a downthrow south of 270 feet, is exceptional in displacing the Trias to the same amount as the Coal-measures.

In the Concealed Coalfield the succession of the Coal-measures above the Top Hard and Barnsley Coal is known from sections afforded by several borings and a few coal-shafts, and proves approximately identical in character and thickness with that known in the exposed coalfield. That is to say, the measures and coals correspond on east and west lines and change from north to south, as in the exposed coalfield.

The Top Hard Coal proves of excellent quality throughout Nottinghamshire, and locally (Gedling) the High Hazles is an excellent house coal. Variations in the thickness of the Top Hard correspond to those known in the proved areas. In the Yorkshire portion of the concealed area the Barnsley Coal maintains its character, and below it the Dunsil Coal is of workable thickness. Below the Top Hard of Nottinghamshire, the Deep Soft, Deep Hard, and Low Main (Tupton) coals have been proved in the Ollerton

district to retain the character and thickness of these seams in the exposed coalfield to the west.

The structure of the concealed coalfield is found more complicated than perhaps was contemplated. Thus the



Bore Holes shown thus: ● Collieries shown thus: ■

FIG. 36.—MAP OF THE CONCEALED NOTTINGHAMSHIRE COALFIELD
Scale, one inch = 8 miles.
Figures give depths to Coal-measures in feet below O.D.

Don Fault system maintains its course and traverses the concealed coalfield in the Doncaster district, and the Brimington anticlinal faulted fold continues under the Permian and Trias east-south-east of Mansfield; but the faulted east and west southern boundary of the exposed coalfield,

east of the Erewash, bends southwards, and it is interesting to find a full development of Millstone Grits in the Ruddington Boring five miles south-south-west of Nottingham City.

The axis of the basin, south of a line drawn between Mansfield and Newark, lies somewhere between the neighbourhood of Edingley and Thurgarton. The Coal-measures certainly dip eastwards and north-eastwards up to a line joining Thurgarton and Edingley, and then rise to the north-east in the direction of the Southwell (Kirklington) and Kelham borings. North of the Mansfield-Newark line the position of the axis is uncertain. It is known that the Top Hard inclines eastward up to a line joining Welbeck Colliery and Rufford Colliery, but somewhat east of this line the measures commence to rise up to the east between Ollerton and Wellow, Rufford and Bilsthorpe. Information is wanting as to what happens north of Manton Colliery, west of Retford, and the recent developments in the Doncaster district. There is some reason to suspect that Thorne Colliery lies slightly east of the synclinal axis, and that the Barnsley Coal is rising to the east.

The western portion of the concealed coalfield, as previously stated, is clearly marked by a long line of collieries between Nottingham and south-east of Leeds. Its northern, eastern, and southern boundaries still remain to some extent conjectural. In 1871 the limits of the coalfield were hypothetically extended to a line drawn a little south of the Ouse at Selby, and close to the eastern and northern banks of the Trent between Selby and Nottingham, thus roughly making the concealed part of the coalfield of about equal size to the exposed area. In 1905 the northerly line was practically adhered to, but the eastern and southern area was extended into a huge protuberance stretching nearly to the North Sea and well into the Fen Country. Since 1905, however, many explorations tend to show that a reduction to the more reasonable limits of 1871 is nearer the truth.

Though the limits of the northern boundary are uncertain, borings in the neighbourhood of Selby show that the Coal-measures extend some distance north of the Ouse; but whether they terminate south of a possible easterly prolongation of the anticlinal axis along the Wharfe, or whether this axis swings to the north-east, and thus carries with it a prolongation of Coal-measures up the Vale of York, remains unproved. The borings round Selby, and the one near Market Weighton which proved over 3,000 feet of

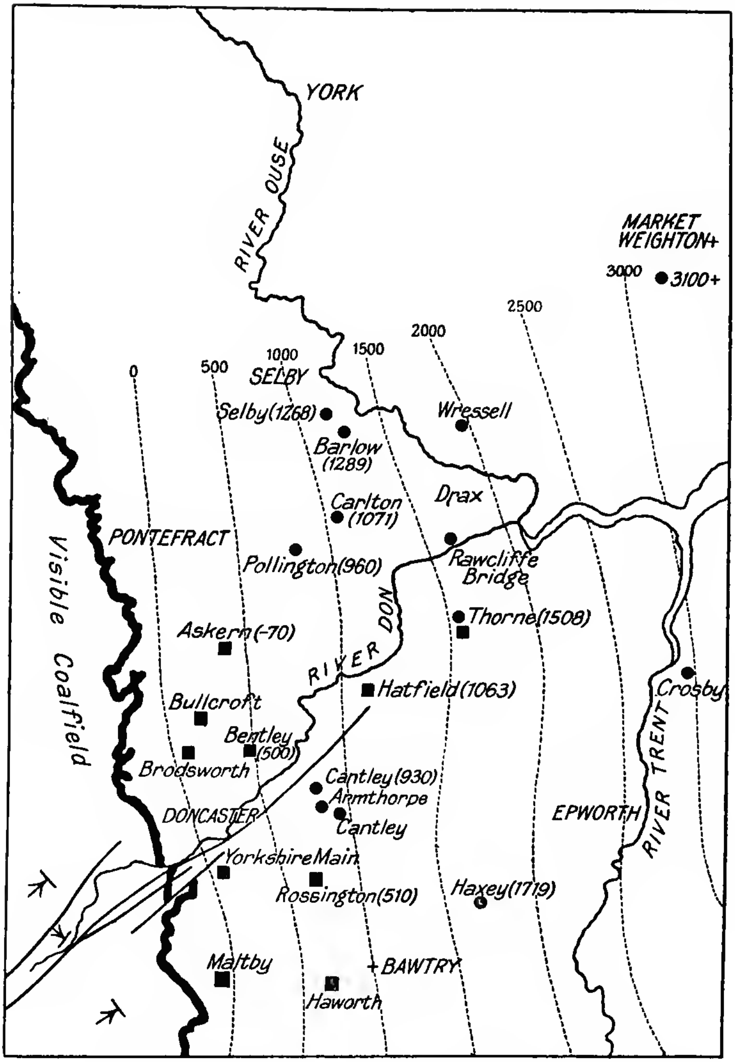


FIG. 37.—SKETCH MAP OF THE CONCEALED YORKSHIRE COALFIELD.
Scale, one inch = 8 miles.
Figures give depths to Coal-measures in feet below O.D.

Permian and Trias strata, show that the Coal-measures, if they exist to the north and north-east of Selby, lie at considerable depths.

The eastern extension of the coalfield between the mouth of the Trent and Carlton-on-Trent remains at present unproved. The little evidence available indicates that the synclinal axis lies west of the Trent; if, however, the Barnsley Coal should extend east of the Trent, it lies under a cover of Permian and Trias not less than 2,500 feet in thickness between the Humber and Gainsborough, and between 2,000 and 2,500 feet between Gainsborough and Carlton. South of Carlton, the Trent forms the eastern limit of the Middle Coal-measures up to Newark. South of Newark the Trent bends to the west, so that the river no longer coincides with the eastern boundary.

South of the Trent at Nottingham borings at Owthorpe and Clipston show that the Middle Coal-measures extend south of these localities, but for what distance remains wholly unproved.

Cover.—Between the deposition of the highest Coal-measures (Keele Beds of the Thurgarton and Farnsfield borings) and the laying down of the Permian and Trias sediments the Carboniferous rocks were folded and fractured and pared down by erosion to an extent equal in amount, but vastly different in character from that of the pre-Permian denudation of the Carboniferous rocks on the west and south of the Pennines. On the west and south, the newer formations fill deep rock hollows in Carboniferous rocks, or wrap round isolated hills of irregular older rocks. On the east side, north of the Trent at Nottingham, the Permian sediments rest on an even surface of carboniferous strata sloping east with great regularity; so regular is its slope that it is possible to contour its buried surface for every 100 feet fall (Figs. 36 and 37). North of the Trent the newer formations are of Permian and Trias age; south of the Trent a gradually increasing thickness of Lias comes on.

The Permian formation commences near Nottingham City, and increases at a uniform rate to over 900 feet at Market Weighton, a distance of sixty-four miles. At the base lies a breccia bed from 1 to 8 feet thick, invariably present between Nottingham and Retford. A little north of Retford it is absent or is locally replaced by quicksand, which is thickest at the outcrop and rarely exceeds 10 feet in thickness. Pale grey clays succeed, and these are not unlike Coal-measures, but invariably contain *Lingula credneri*, and usually many other Permian fossils. They are well defined at outcrop, but in borings to the east and north vary greatly

in character, and by the intercalation of limestones often become inseparable from the Lower Magnesian Limestone. The latter is usually a compact dolomitic limestone, from 10 to over 300 feet in thickness, containing much anhydrite in borings north of Retford. The Middle Marls above, from 10 to 150 feet thick, consist of chocolate-red marls with beds of gypsum, anhydrite, and rock salt, in the Humber district. The Upper Permian Limestone is a cream-coloured rock commencing near Retford and gradually increasing northwards to 100 feet. The Upper Marls resemble the Middle Marls, and are present wherever the Upper Limestone is developed.

The Trias is composed of the Bunter Sandstone, Keuper Sandstone, and Keuper Marls. South of Retford the three subdivisions are distinct, but to the north of Retford the Trias consists of soft red sandstones—grey locally, and somewhat resembling a Coal-measure sandstone in the Vale of York—and Keuper Marls. Either the Keuper Sandstones have changed to marls or the Keuper Sandstones are here of Bunter type. The Keuper Marls retain throughout the area the character of loamy red marls with layers and 'stringers' of gypsum. The Bunter increases from 250 feet at Clipston, south of Nottingham, to 2,000 feet at Market Weighton. The Keuper Marls, 661 feet thick at Owthorpe, become 908 feet at South Scarle, eight miles north-east of Newark, and 1,003 feet at Scunthorpe. The Lower Lias thickens from 290 feet in the north of Lincolnshire to about 700 feet in the south of the county.

CHAPTER XIV

THE LEICESTERSHIRE COALFIELD

THE Carboniferous rocks of Leicestershire occupy an ancient depression situated between the Cambrian rocks of the Warwickshire Coalfield and the pre-Cambrian rocks of Charnwood Forest north of Leicester. The coalfield includes an area of about 60 square miles in the county of Leicester, together with about 16 square miles in South Derbyshire. The Coal-measures at the surface occupy a rectangular area of about 24 square miles in extent, with Ashby-de-la-Zouch near the centre. The concealed coalfield has its main extension to the south-east, and has been proved to reach a short distance south of Desford and to terminate on the north-east against a fault bordering the pre-Cambrian rocks of Charnwood Forest. There is also an important extension under the Trias on the west side of the coalfield.

The net available quantity of coal remaining unworked is estimated at 1,825,458,551 tons.

The Carboniferous Limestone, succeeded by Limestone Shales, and these in turn by Millstone Grits, crops out around Ticknall, Melbourne, and Breedon-on-the-Hill, situated on the north-east side of the coalfield. The limestone and shales, the latter only a few feet thick, appear to be bounded by faults, and the limestone of Breedon is lower in the series than that of Ticknall. It has been met with in a boring south-west of Desford, but is only 20 feet thick; and it also appears to have been reached in borings at Piper Wood near Shepshed, at Ibstock, at Nailstone, and at Lount.

The Millstone Grits consist of pebbly sandstones at the base, succeeded by massive sandstones and grits, and these in turn by soft sandstones, occupying the centre of the syncline west and south of Melbourne. The Coal-measure succession consists of:

Upper	Etruria Marls	Red clays with Espley Rocks; in borings in the west.
Middle	Productive Series	Grey sandstones, clays, and numerous coals; base is Roaster Coal in east, Kilburn Coal in west; 600 to 700 feet east, 2,200 feet west.
Lower	Unproductive Series	Grey shales and sandstones with few and thin coals; 500 to 600 feet.

Of the Lower Coal-measures very little is known. They crop out principally in the northern part of the area between Ashby and Ticknall, bounded by faults on the north-east and south-west, and with an indefinite boundary on the north-west and south-east. The only seam that has been worked is the Pistern Hill Coal, from 2 to 3 feet thick. A few plant and fish remains have been recorded. The plants are said to include species indicating a lower horizon than those in the Productive Series.

The Middle Coal-measures occur in an eastern and western area, separated by an anticlinal fold of Lower Coal-measures. The thickness and character of the measures in the two areas are distinct, and there is great difficulty in correlating the seams in the one district with those of the other. On the eastern side the Roaster Coal is generally considered as the base of the Productive Series. On the western side the Kilburn Coal is the lowest workable seam. The highest Coal-measures known in the coalfield are found on the western side at the outcrop and in borings west of Church Gresley.

In the eastern coalfield the average thickness of the coals and of the strata between them is as follows:

	Feet.		*Feet.*
Stone Smut Rider	3–4	Strata	40–60
Strata	30–40	Stinking Coal	2–4
Stone Smut Coal	3–6	Strata	50–60
Strata	10–20	Main Coal	5–7
Swannington Coal	2–4	Strata	10–30
Strata	30–50	Smoile Coal	3–4
Soft Coal	1–2	Strata	30–40
Strata	30–40	Upper Lount Coal	2–4
Slate Coal Rider	1–2	Strata	30–50
Strata	10–20	Middle Lount Coal	4–6
Slate Coal	4–9	Strata	5–30
Strata	20–60	Nether Lount Coal	4–6
Yard Coal	2–5	Strata	30–120
Strata	20–40	Roaster Coal	2–4
Rattle Jack Coal	1–3		

The flora is better known than the fauna; among the latter *Lingula mytiloides* and *Glyphioceras* have been recorded from between the Roaster and Main coals; several species of *Carbonicola*, including *Carbonicola robusta*.

At Whitwick Colliery, and as far south as Ellistown, a sheet of dolerite overlies the Coal-measures. It is 21 feet thick in the Whitwick Colliery, but thins out towards the north-west and south; it is absent at Snibston Colliery on the west and at Nailstone Colliery and Bagworth on the south. It is thus confined to an area of about four square miles. The molten rock appears to have come up along a fault (Thringstone), and in this respect agrees with the igneous intrusions of Kelham and Southwell in the Nottinghamshire Coalfield (p. 188); but while the rock at Whitwick is allied to the dolerite of South Staffordshire, the igneous rock of Southwell compares more with the toadstones of Derbyshire. When in contact with a seam of coal, this is charred and the rock itself is converted into white trap in which the original minerals are replaced by carbonates and kaolin. On the other hand, the Triassic strata do not appear to be changed even when in actual contact. The intrusion, then, is apparently earlier than the Triassic period, but later than the Coal-measures. In the Whitwick rock the olivine grains are rounded, passing into serpentine along the edges of the crystals and in their centres. The augite forms large ophitic plates, is of a purplish-brown colour, and encloses many lath-shaped plagioclase felspars. Iron oxides and apatite are present as accessory minerals; and as secondary products there occur chlorite, serpentine, analcime, and other zeolites.

The western district, or, as it is sometimes called, the South Derbyshire Coalfield, is better known both stratigraphically and palæontologically. In the upper part of the measures valuable clays are associated with the coals; there are several open sections of the measures, and therefore more facilities are afforded for examination. The coals are arranged in the following order, with the thickness apart stated in feet:

	Feet.		*Feet.*
Strata	40	Strata	125
Coal	6	Block or Watson Coal	3–6
Strata	60	Strata	150–250
Ell Coal	4–9	Five Feet or Little Coal	3–5
Strata	200	Strata	150–180
Dickey Gobbler Coal	3–4	Main Coal	12–16

	Feet.		Feet.
Strata - -	20–40	Strata	20–80
Little Woodfield Coal	3–5	Eureka Coal	4–5
Strata -	100–140	Strata -	50–90
Woodfield Coal	5–8	Stanhope Coal	2–5
Strata -	30–70	Strata -	200–280
Stockings Coal -	5–8	Kilburn Coal	4–5

The seams worked are the Stanhope, Eureka, Stockings, Woodfield, Main, and Little coals. All these are of a bituminous type, furnishing house and manufacturing coals. The Main Coal is the standard seam of the district. It consists of two seams in the north which unite in the south and form one seam from 14 to 16 feet thick. It includes several layers of coal, each of which receives a name, those termed 'spire' generally furnishing the best marketable coal. Between the Main and Five Feet coals a thin coal is locally associated with 2 feet of bastard cannel, and also with a coal between the Five Feet and Watson coals. The measures for some distance below the Ell Coal and those above form the 'Pottery Clay' Group. They cover the higher ground at Church Gresley and Swadlincote, and are found over the Moira district to near Donisthorpe, where also some of the highest Middle Measures, consisting of coarse, gritty sandstone, crop out and extend up to the Great Boothorpe Fault. The clays of Wooden Box furnish the 'crucible' clays used at the steel-works in Sheffield.

The Etruria Marls have been penetrated in borings to the west of Church Gresley, but the records of these borings have not been made public.

The fossil flora is somewhat rich and varied, but the fauna, as at present recorded, is meagre. The most interesting band is that containing a marine fauna associated with the Main Coal. *Anthracomya phillipsi* has not been recorded from any part of the sequence.

The general structure of the coalfield consists of a central anticline that brings the Lower Coal-measures to the surface in the central part of the area. This arch is bounded on the east by a fracture—Thringstone Fault—bringing productive measures, inclined west, against Lower Carboniferous rocks. On the west side a fault—Linton Fault—introduces Upper Coal-measures under Trias on the west against the Productive Measures of the Moira Coalfield on the east. The Thringstone, Cole Orton, or Boundary

Fault, is estimated to have a throw down west of over 2,000 feet near Whitwick. The fault is at the surface between Ticknall and Staunton Harold, where it disappears under the Trias which passes unbroken across the dislocation in the Carboniferous rocks.

The Linton Fault has a proved downthrow of 816 feet on the west side of Netherseal Colliery. From this place it runs north to Linton village, where it was driven through in a heading from the Coton Park Colliery. It has been worked up to in the Netherseal workings, and the measures proved by borings show that the Coal-measures are much disturbed in this district.

Two important faults dislocate the measures in the Moira district. Of these, the Moira Fault, two and a half miles east of Netherseal, throws the measures down to the east, bringing the Main Coal slightly below the level of the Eureka Coal.

One mile farther east the Boothorpe Fault, a north and south fault, throws down the measures above the Dickey Gobbler Coal against the Rafferee (Stockings) Coal near Woodville, thus giving a downthrow west of nearly 1,000 feet at this spot.

At Whitwick the Thringstone Fault brings the steeply inclined measures on the horizon of the Yard Coal (p. 195), against the pre-Cambrian rocks of Charnwood Forest. This does not necessarily imply that the whole of the Carboniferous rocks were cut out by the Thringstone Fault, since it is probable that facing the pre-Cambrian rocks there lay a deep hollow that was filled first with the Lower Carboniferous rocks, followed by the deposition of the Lower Coal-measures, and these in turn by the Middle Coal-measures.

Below the Roaster, and possibly identical with the Pistern Hill Coal, a seam of cannel 7 feet in thickness and full of pyrites was worked at Heath End Colliery, Staunton Park.

The Main Coal is a steam, house, and manufacturing coal; the Roaster a manufacturing coal. Several other coals come in over the southern part, such as the Seven and Five Feet coals above the Main Coal at Desford and the Ten Feet Coal of the same colliery; the Upper Main of Desford, Bagworth, and Ellistown; the Yard of Snibston; the Minge and Upper Main of Whitwick. These are chiefly house and manufacturing coals.

A development of the coalfield may be looked for to the south-west of the continuation of the Thringstone Fault, beneath the Trias, south of Whitwick, and to the west of the Linton Fault.

East of the Charnwood Forest there is little prospect of a concealed coalfield. Borings at Crown Hill, near Leicester, entered pre-Carboniferous rocks; and of two borings near Hathern, one reached rocks older than the Coal-measures and probably older than the Carboniferous. The Leicestershire Coal-measures, it would appear, do not occur under the Valley of the Soar, and whether they come in farther to the east remains to be proved; a boring at Ruddington, however, suggests that to the east of the Charnwood range the Millstone Grits form the first belt under the Trias.

South-west of the Thringstone Fault borings round Market Bosworth prove that the pre-Carboniferous rocks rise up in this direction, and that a ridge composed of older rocks separates the coalfields of Leicestershire and Warwickshire. A boring to the south-west of Desford Colliery shows that only a diminished representative of the Lower Carboniferous strata lies between the Trias and the buried pre-Cambrian strata. Borings to the south-west of the Linton Fault, at the Netherseal workings, give rather contradictory results as to the structure of the buried coalfield. They show conclusively, however, that the pre-Triassic surface slopes steeply to the south-west, and that the Triassic rocks quickly attain a thickness of at least 1,200 feet. While bearing in mind that the Coal-measures do not extend in an

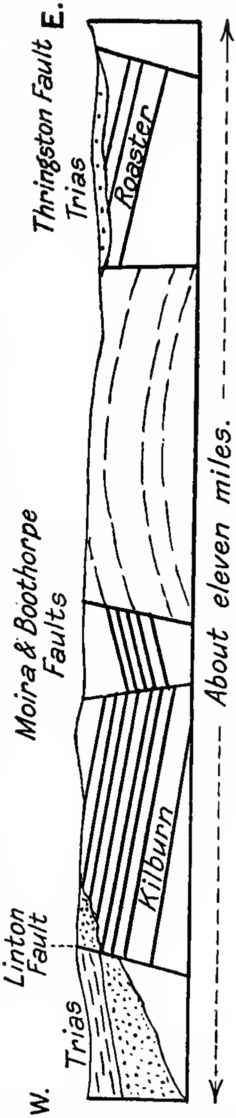


Fig. 38.—Section across the Leicestershire Coalfield.

unbroken sheet south-west of the Charnwood Hills, and that there are tracts in which the Coal-measures are absent, reasonable hopes of extensions in the direction of the Warwickshire Coalfield may be entertained.

Cover.—The rocks newer than the Coal-measures consist of the unconformable Bunter and Keuper subdivisions of the Trias. In the north-west the Bunter sandstones and conglomerates attain a maximum thickness of 1,000 feet, but gradually thin away to the south-east. The Keuper Sandstone, including the Lower Keuper Sandstones and Waterstones, reaches a thickness of 150 feet in the west and about 100 feet in the south-east. The succeeding Keuper Marl subdivision consists of red and mottled marls, with thin bands of grey and white sandstone ('skerry'), which thicken out locally near the top into a sandstone, called the 'Upper Keuper Sandstone,' 100 feet thick, in a boring near Humberstone. The average thickness of the Keuper Marls is approximately between 600 and 700 feet.

CHAPTER XV

THE WARWICKSHIRE COALFIELD

SITUATED between the coalfields of South Staffordshire and Leicestershire, that of Warwickshire has some characteristics common to both, others peculiar to itself. In the absence of Lower Carboniferous rocks and the presence of a thick bed of coal, and in the general Coal-measure sequence, it resembles the South Staffordshire Coalfield, but differs from those of Leicestershire and South Staffordshire in having a marked development of the higher Coal-measures, and in the absence of igneous intrusions. Structurally it differs from both; and, further, while future developments here lie within the coalfield itself, those of Leicestershire and South Staffordshire are situated along the margins.

Roughly spindle-form in shape, the coalfield extends from Tamworth on the north to Warwick on the south, a distance of twenty-two miles. Its greater breadth, eight miles, is in the latitude of Bedworth. The total area is slightly under 150 square miles, but the major portion of the coalfield is occupied by the highest and barren Coal-measures, to which the productive measures form a narrow fringe on the east and north.

The quantity of coal remaining unworked is estimated at 1,126,981,903 tons.

Both the Carboniferous Limestone and Millstone Grits are absent, and between Atherstone and Bedworth the Coal-measures rest directly, but unconformably, on Cambrian shales. At Dosthill, on the north-west side of the coalfield, Cambrian rocks also form the floor of the Coal-measures, which, so far as is known, were deposited in a hollow of Cambrian rocks that never received any sediments of Lower Carboniferous age, or, if these were ever deposited, they must have been denuded before the area again came within reach of the Carboniferous sedimentation.

The Cambrian rocks consist of an inferior group of

quartzites—Hartshill Quartzites—and an upper shale group —Stockingford Shales, rich in trilobites.

Numerous dykes and sills of igneous rocks traverse the Cambrian strata. These, unlike the dolerite intrusions of Leicestershire and South Staffordshire, do not pierce the Coal-measures, and belong to an older type of igneous rocks, termed 'camptonites,' containing hornblende as an essential constituent.

In appearance the Cambrian shales resemble Lower Coal-measures and the Hartshill Quartzite a silicified Millstone Grit, so much so that both were once mistaken for Carboniferous strata. In the absence of fossils it is certainly difficult to distinguish between a Cambrian black shale and one of Coal-measure age in disturbed regions like Pembrokeshire, though their resemblance to those of the Midland Province is less striking.

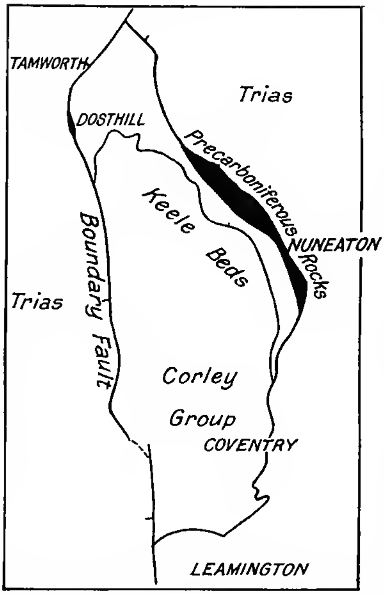


Fig. 39.—Sketch Map of the Warwickshire Coalfield.
Scale, one inch = 8 miles.

The types of Coal-measures occur in the descending sequence given on p. 203.

The different types graduate upwards into each other, and are not stratigraphically separable. On palæontological evidence, based chiefly on the flora, the Lower Coal-measures are considered to be absent, and the sequence to commence with the Middle Coal-measures, but authorities differ widely as to the correlation of the rocks above them (p. 206), especially as to whether the Corley Beds should be included in the Carboniferous sequence or maintain their place in the Permian formation.

The Middle Coal-measures, consisting chiefly of clays and shales, contain all the workable coals and ironstones. Sandstones are feebly developed, though locally around Merevale a coarse, false-bedded sandstone with quartz pebbles forms a distinguishing base, and the Four Feet

Coal is usually accompanied by a sandstone above it. The measures attain a thickness of about 1,000 feet in the Tamworth area, with a gradual diminution southwards. South of Stockingford certain of the coals tend to unite by the dwindling of the intervening measures until at Newdigate Colliery five seams of coal have coalesced to give a thickness of 23 feet 4 inches of coal, forming the compound seam known as the Thick Coal or Hawkesbury Seam. It is doubtful if these five coals are represented over the northern part of the coalfield, and it is only the Seven Feet Coal that certainly extends over the whole of the proved area.

COAL-MEASURES OF WARWICKSHIRE.

Upper	Corley Beds	Red marls and sandstones, conglomeratic sandstones near the base; *Walchia imbricata*, 1,500 feet.
	Keele Beds	Red and purple marls and sandstones, with three beds of Spirorbis limestone; *Pecopteris arborescens*, 1,000 feet.
	Halesowen Sandstone Group	Grey sandstones and shales, with thin coals. Spirorbis limestone towards the top. Neuropterids and Pecopterids abundant, 100 to 450 feet.
	Etruria Marls	Red and mottled marls with green grits (Espley Rocks), 80 to 150 feet.
Middle	Middle Coal-measures	Grey clays, shales, and some sandstones. Numerous coals. *Neuropteris gigantea*, *Lepidophloios laricinus*, 400 to 1,000 feet.

The fossil flora is rich, containing thirteen species common to the Middle and Lower Coal-measures of Britain, and two —*Lepidophloios laricinus* and *Calamocladus charæformis*— which are unknown in the Lower Coal-measures. The abundance of *Neuropteris gigantea* with an absence of typical Upper Coal-measure species also indicate a Middle Coal-measure age for the measures below the Etruria Marls.

The same age is supported by the fauna in that the species of *Carbonicola* most frequently met with are common Middle Coal-measure fossils, while *Carbonicola robusta* is absent. Of importance as indicating a definite horizon are the marine shells found in the roof of the Seven Feet

Coal. They include such typically marine shells as *Aviculopecten, Pterinopecten, Nucula.* Fish beds have been noted in association with the Bench and Double coals, the Seven Feet Coal, and the constituent seams of the Thick Coal. A few rare Crustaceans are recorded from the Coal-measures of Baddesley, Newdigate, and Amington collieries.

The Etruria Marl type of sediment is not well developed except in a few clay-pits around Tamworth and at Haunchwood. Showing a tendency to lose their red colour, they are not infrequently indistinguishable from the Middle Coal-measures except where they contain Espley Rocks. A few *Calamites, Ostracoda, Spirorbis* in limy nodules, constitute a sparse and generally badly preserved flora and fauna.

The Halesowen Sandstone Group is uniformly developed, and maintains over considerable areas an average thickness of 400 feet. It is susceptible of subdivision into a lower grey sandstone group and an upper grey shale group, with a band of Spirorbis limestone, called the 'Index Limestone,' 150 feet from the top and 2 to 6 feet thick, with abundant, large, and well-preserved specimens of *Spirorbis.* Shales near the base and near the top are often red in colour, showing the gradual passing away of the Etruria Marls phase or the oncoming of the Keele phase. The sandstones are porous and yield large quantities of water in sinking shafts through them. The flora consists of thirteen species, with specimens of *Pecopteris* and *Neuropteris* abundant. The fauna is confined to *Spirorbis.*

Two or three thin coals are generally recorded in borings and shaft sinkings, but they have no commercial value.

The Keele Group consists essentially of red and purple sandstones with purplish-red marls, with an occasional development of grey and pink-coloured sandstones. There are no coals. Fossils are rare, and are represented by *Spirorbis* in thin bands of dark grey limestone and by four species of plants, among which *Pecopteris arborescens* is a typical Coal-measure plant. The occurrence of *Walchia,* always badly preserved, indicates a high horizon in the general Coal-measure sequence.

Spirorbis limestones are two or more in number, and are not as a rule persistent except one at 150 feet from the base and a higher one beneath the Exhall conglomerate, which have been traced over considerable areas.

The Exhall conglomerate is locally developed around

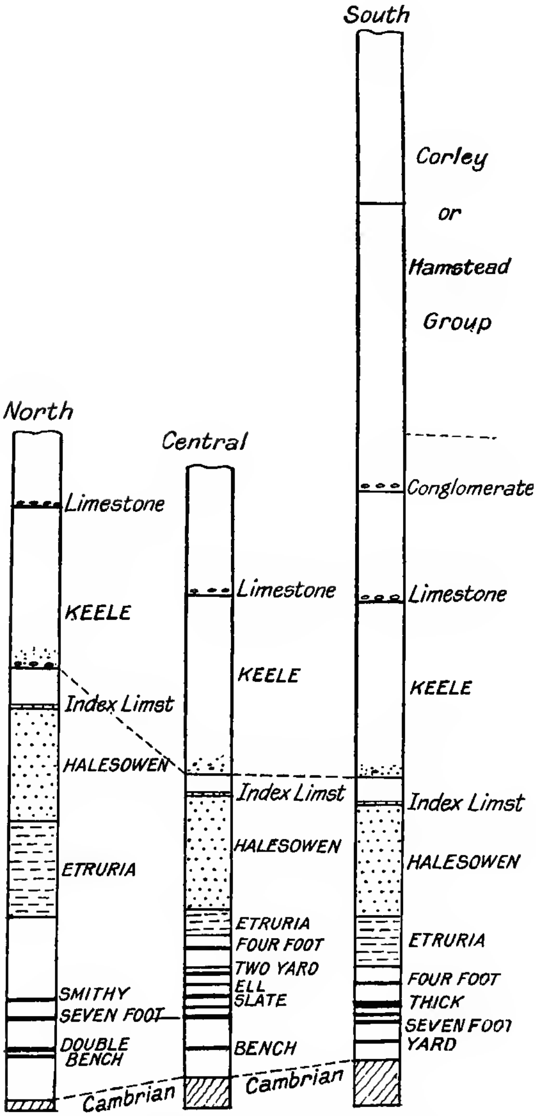


FIG. 40.—SECTIONS, WARWICKSHIRE COALFIELD.
Scale, one inch = 500 feet.

Exhall and Arley Station. It is characterized by the occurrence of pebbles of Carboniferous Limestone. The sandstones contain much water, held mainly in fissures. In sinking the shafts of the Coventry Colliery the water amounted to 2,600 gallons per minute, but was successfully combated by the cementation process.

Around Corley and in the neighbourhood of Coventry a massive red sandstone with lenticles of conglomerate succeeds the red sandstones and marls of the Keele Group. Finer-grained red sandstones interstratified with crimson marls lie above the Corley Sandstone, and these in turn are succeeded by crimson marls and fine-grained red and grey sandstones which extend southwards from the Birmingham and Rugby railway past Kenilworth to Warwick. The full thickness of the Corley and Kenilworth sandstones and marls is not known, but outcrop measurements give a thickness of not less than 1,500 feet. The Corley and Kenilworth sandstones rest conformably on the Keele Group, and not unconformably, as has been sometimes stated. Stratigraphically, then, they are related to the Carboniferous Keele Group. The fossil evidence of their age is scanty and not conclusive, and has been taken as indicating a Permian age by some authorities and as a Stephanian age (Upper Coal-measures of the Continent) by others.

The commonest fossil is *Walchia imbricata* and around Allesley the silicified tree trunks of *Dadoxylon*, which is apparently a Carboniferous plant with *Cordaitean* affinities. It is doubtful whether the Labyrinthodont (*Dasyceps*, *Oxynotus*) remains recorded from the district around Warwick were obtained from quarries in the Bunter or in the Kenilworth Group. But whatever their age, the Corley and Kenilworth groups are conformable to the Keele Group, and the productive Coal-measures can be expected to occur beneath them over a wide stretch of country between Corley and Warwick.

The general structure of the coalfield is that of a broad basin (syncline) having a north and south axis which pitches to the south, and so brings in on the south of Polesworth successively higher beds. On the east between Coventry and Atherstone the measures rise up sharply against the anticline of Cambrian rocks. North of Atherstone and along the whole length of the western margin of the coalfield the measures rise up sharply towards faults,

termed the Eastern and Western Boundary faults. Between Bedworth and Leamington the eastern margin of the coalfield is concealed beneath Trias. The depths at which the Coal-measures lie outside the Boundary faults is unknown, as is also the eastern limit of the coalfield under the Trias between Bedworth and Leamington. Within the coalfield the greatest depth to the base of the Coal-measures does not exceed 3,000 feet. Faults, except the Boundary faults, are of no great consequence, the most important structure consisting of the Arley anticline that brings up the Halesowen sandstone in a narrow belt surrounded by Keele sandstones and marls. This structure determined the location of the Arley pits, which, until recently, remained the only shafts reaching the coals towards the centre of the coal-basin.

The coals are of the bituminous types, and are used for domestic and manufacturing purposes. Bastard cannels occur in limited quantities only, and are not mined separately. A portion, termed 'spires' of the Slate Coal furnishes a steam coal used in particular manufactories in which a clean coal is indispensable, but the coalfield does not yield any seam of outstanding and exceptional value. In the northern part of the coalfield the coal, in seams of 2 or more feet in thickness, amounts to 35 feet, distributed into about a dozen seams, of which the Seven Feet Coal is the thickest. This is the chief coal, but below it the Double and Bench coals are workable. Above the Seven Feet Coal the Rider Coal is also worked. In the Stockingford area the Seven Feet Coal and the seams below it are worked. In this area either fresh seams make their appearance above the Seven Feet Coal or they represent certain, but not distinctly related, seams of the north, which thicken out southwards and tend to unite, until at Newdigate they form the compound seam known as the Thick Coal or Hawkesbury Seam.

At Newdigate the Thick Coal consists of the Two Yard (6 feet); parting 6 inches; Bare (2 feet); Ryder (5 feet 5 inches); parting 4 inches; Ell (3 feet 3 inches); parting 2 inches; Slate (6 feet 4 inches), making 23 feet 4 inches of coal. This Thick Coal remains the dominant seam up to the present southerly limit of working at the Coventry Colliery. The partings increase in thickness towards the outcrop—that is, to the east and south-east. At Binley

Colliery the Thick Coal shows deterioration. The Seven Feet Coal and the seams below it practically remain intact beneath the Thick Coal area.

Faults and disturbances, as previously stated, do not seriously affect the working of the coals in Warwickshire, except in the vicinity of the Boundary faults. Extensive barren areas ('washouts') and smaller waste ground ('rolls,' 'horses') affect the Rider and Thick coals in some districts, but the chief obstacle to successful mining is the inherent difficulty in working the Thick Coal at great depths, necessitating the opening out of large areas before a considerable output is obtainable.

With the exceptions of the Arley and Coventry collieries, the coal-pits are situated in the northerly part of the coal-field and along or near the eastern outcrop. Over an area of roughly sixty square miles, situated between the Midland Railway at Arley and the London and North-Western Railway at Tile Hill, the coals are practically untouched, but have been proved by the workings of the Coventry Colliery and Packington Boring. South of Tile Hill the ground occupied by the Kenilworth Sandstone Group is unproved. Possibly, from the evidence at Binley Colliery, the coals are of a different character in the eastern part of this area to those in the north.

In the southern area and in that north of Tile Hill the chief difficulty in sinking will be the amount of water in the Keele, Corley, and Kenilworth sandstones, but this should not occur in greater quantity than at the Coventry Colliery. There is no doubt that extensions of the coalfield can be expected outside the Boundary faults on the north-east and west of the coalfield, but the actual depths to the coals remains uncertain. West of Maxstoke and Berkswell they are certainly at considerable depths.

Judging by the results obtained by the borings at Stretton Baskerville, Binley, and Brandon, the Coal-measures are absent and the covering of Trias rests on rocks older than the Coal-measures east of a line between Wyken and Brandon; but to the west of this line the general structure of the coal-field suggests that, going west, the Trias rests first on a belt of Middle Coal-measures, and then successively on the higher members of the Coal-measure sequence. Thus an experimental boring on or near to the continuation southwards of the Wyken-Binley line would possibly encounter

productive measures under a cover not exceeding 1,200 feet in thickness. A boring placed farther west would reach barren measures under the covering formations, which, however, would be less in amount, and thus compensate for an extra thickness of the barren Coal-measures above the productive Middle Coal-measures.

CHAPTER XVI

THE SOUTH STAFFORDSHIRE COALFIELD

INCLUDED in the South Staffordshire Coalfield is a spindle-shaped area of Coal-measures forming the visible coalfield, and appearing as an island of Palæozoic rocks surrounded by the Trias or New Red Sandstone formation, beneath which the coals have been followed into what is called the 'concealed' coalfield. The total area of the coalfield is 149 square miles, the visible coalfield extending from Brereton on the north to Bromsgrove-Lickey, a distance of about 26 miles, with a width of about 9 miles between Wolverhampton and Barr Beacon. The southern half of the visible coalfield is thickly populated; with Birmingham and Wolverhampton situated on the marginal Triassic rocks and Keele Beds.

The visible coalfield is estimated to contain a net reserve of 874,433,072 tons; and the concealed area a reserve of 541,015,000 tons.

Carboniferous Limestone and a feeble representative of the Millstone Grits have been proved in borings and sinkings to the north of the visible coalfield, but over the central and southern part and in its neighbouring extension the Coal-measures rest on an irregular floor of Silurian rocks. These form the conspicuous ridges of Sedgley, Wren's Nest, Dudley Castle Hill, and Netherton, and give rise to an extensive platform around Walsall. Similar ridges and platforms of Silurian rocks have been encountered in the concealed coalfield south of a line on the latitude of Sedgley and West Bromwich. The shales, termed 'bavin' by the miners, and some of the Silurian sandstones are not unlike pale-coloured Coal-measures, for which they have been mistaken, but it is rarely difficult to find typical Silurian fossils in them. The upper part of the Silurian (Ludlow Beds) of Netherton consists of red sandstones and shales somewhat resembling red Upper Coal-measures; but the fauna, though not prolific, is distinctive.

The accompanying limestones of the Silurian rocks are important as yielding a flux to the blast furnaces.

Sometimes the Coal-measures are inclined at the same, or nearly the same, angle as the Silurian, and the structures found in the Coal-measures moulded on older ones in the Silurian rocks. Nevertheless, the two formations are often violently discordant, as is well seen in a section at Brewins, near Netherton. It is noticeable also that the oldest Silurian rocks—Llandovery and Woolhope Beds—occur in the east around Barr Beacon, and that the newest — Wenlock and Ludlow Beds—are met with in the west at Dudley, Sedgley, and Netherton; the Middle Coal-measures, however, resting on the Silurian of Barr Beacon, belong to approximately the same horizon as that of Dudley and Netherton. At the southern end of the coalfield, in the Lickey Hills, Upper Coal-measures repose on Wenlock Beds. It is apparent that the Silurian rocks existed as banks, and in the southern part of the coalfield as promontories or islands, against which the Coal-measures were deposited. This irregular floor, however, sloped on the whole to the north, so that in this direction older Coal-measures and, as previously mentioned, even Carboniferous Limestone and Millstone Grits are met with. It is in a northerly direction that the Coal-measure sediments expand and that the composite coal-seams of the south split into their several components, in addition to the incoming of several seams of coal.

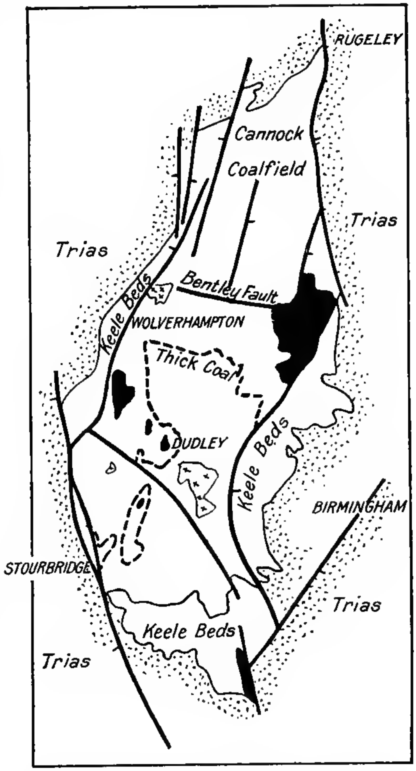


FIG. 41.—SKETCH MAP OF THE SOUTH STAFFORDSHIRE COALFIELD.
Scale, one inch = 8 miles.

The Carboniferous Limestone was, until recently, supposed to be absent, but has been met with in the Fair Oaks Colliery, west of Rugeley. Farther north, in a boring at Wolsley Park, the Coal-measures rest on sandstones comparable to the Millstone Grits of North Staffordshire, but this apparent upward succession is possibly fallacious, for the conviction is gradually gaining ground that a considerable hiatus separates the Carboniferous Limestone and the beds called Millstone Grits from the Coal-measures.

The following Coal-measure sequence belongs to the general Midland type, and in many respects is similar to that of North Staffordshire:

Upper	Hunnington (Hamstead) Beds	Red sandstones, red marls, and calcareous conglomerates; no coals; over 1,500 feet.
	Keele Beds	Red and purple sandstones and marls, with Spirorbis limestones; 900 feet; no coals.
	Etruria Marls	Mottled and chocolate-coloured marls, with green grits and breccias (Espley Rocks); 300 to 700 feet; thin coal-seams.
	Halesowen Beds	Grey shales with Spirorbis limestone, grey sandstones, shales, and thin coals; 400 to 500 feet.
Middle	Middle Coal-measures	Grey shales and fireclays, some sandstone; numerous coals; 600 to 2,000 feet.

This classification is essentially based on differences in lithological characters. The groups graduate upwards; and locally, one group may assume the characters of another, as near Walsall Wood, where the Etruria Marls take on in part the character of the Keele Beds, and at Hamstead Colliery, where the Halesowen Sandstones are partly red. Such variations, however, are of rare occurrence, and usually some distinguishing peculiarities are present.

The Middle Coal-measures expand from 600 feet at the south end of the coalfield to 2,000 feet at the northern end, a rate of 54 feet per mile; but this expansion is not uniformly distributed, the measures above the Thick Coal participating most in the northerly increase. The bulk of the measures consists of unstratified grey clays ('clunches,' 'fireclays'), grey shales ('binds'), sandstones, and the arenaceous mem-

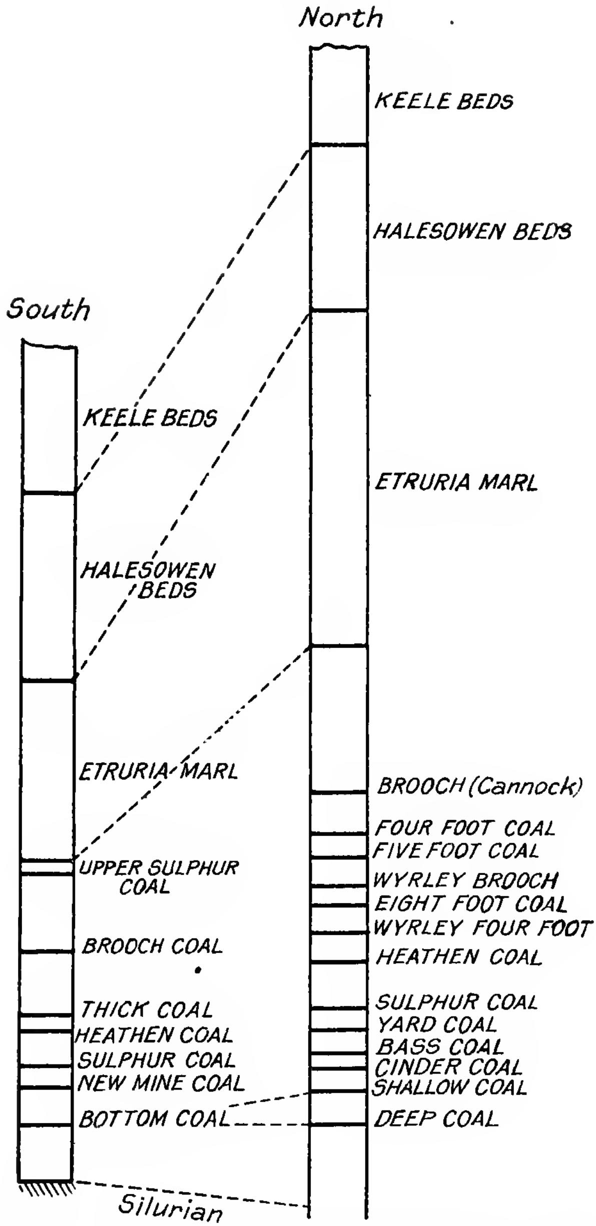


FIG. 42.—SECTIONS, SOUTH STAFFORDSHIRE COALFIELD.
Scale, one inch = 400 feet.

bers generally are not strongly developed. South of the Bentley faults (p. 217) exposures are numerous, but to the north the Middle Coal-measures are for the most part hidden by Drift sands and the Trias of Cannock Chase. In the latter case the character of the measures is ascertained almost entirely from the records of numerous colliery shafts.

Different parts of the succession are not conspicuously indicated by marked divergencies in character. Locally at the Lye, Netherton, Essington, and in some of the Cannock Chase collieries, the base is a coarse conglomerate, containing large pebbles of Carboniferous Limestone, Lickey quartzite, and other locally derived rocks, set in a sandy matrix. Except that many of the pebbles are well rounded, these coarse detrital rocks resemble the Espley Rocks of the Etruria Marls.

Below the Deep (Bottom) Coal the measures usually consist of grey and black shales containing the nodular layers of argillaceous carbonates of iron called 'Diamond,' 'Silver Threads,' or 'Blue Flats' ironstones, formerly extensively worked in the Walsall and Bentley districts. In pits over Cannock Chase these measures are sometimes of a red colour. Above the Deep Coal the numerous seams of coal (section, p. 213) characterize the sequence, the intervening measures consisting chiefly of shales and clays containing argillaceous carbonates of iron in nodules and thin layers, and formerly extensively worked under the names of 'Gubbin,' 'Balls,' 'Pennystone,' 'New Mine,' and 'Pennyearth' ironstones over the area south of the Bentley faults. Sandstones are locally associated with the Thick Coal and with the New Mine Coal. North of the Bentley faults eighteen separate coals occur between the Deep Coal and the base of the Etruria Marls, a number reduced to seven south of the Bentley faults. It is generally accepted that the diminution in the number of the seams has arisen from the union of two or more coals. The Heathen Coal, the sixth seam above the Deep Coal, is common to both areas; but in the south the Bottom Coal is formed by the union of the Shallow and Deep coals, and the New Mine by the coalescence of the Bass and Yard coals. Above the Heathen Coal, Jukes regarded the Thick or Ten Yard Coal of the south as the equivalent of ten seams that are separated in the north; but as the Thick Coal crops out before the Bentley faults are reached, the formation of the Thick Coal by the union of ten northern seams remains a matter of inference.

The flora of the productive Coal-measures is very rich in species, and clearly indicates their Middle (Westphalian) Coal-measure position in the general classificatory scheme of the English Coal-measures. Marine shells are recorded from the White Ironstone measures around Rowley Regis, in the Pennystone Ironstone Measures of Oldbury, above the Brooch Coal of Hamstead Colliery, and below the Cannel Coal near Cannock. *Carbonicola robusta* occurs 30 feet below the Deep Coal of the Cannock and Rugeley collieries.

The Middle Coal-measures graduate upwards into red, mottled, unstratified marls, which are identical with the Etruria Marls of North Staffordshire, and it is convenient to retain this nomenclature, especially as it has been generally adopted by mining engineers throughout the Midland Province. They correspond to the Brick Clays of Jukes and the Old Hill Marls of some authors. At least 700 feet thick in the Cheslyn Hay and Essington district, they are also well developed around Aldridge and over the southern part of the district, and form an important group in supplying the raw material of the famous blue brick of South Staffordshire.

Though red, purple, and ochreous marls predominate, bands of grey and black marls and shales occur on a few horizons. Coarse red, green, and yellow bands of breccia (Espley Rocks) are common, and along the southern outcrop contain large subangular blocks of Lickey quartzite, pre-Cambrian igneous rocks, and other foreign material. Occasionally, as at Walsall Wood, red sandstones are developed on a considerable scale, and the beds assume the character of the Keele Group.

The Etruria Marls decrease in thickness eastwards, and at Hamstead Colliery are less than 200 feet thick. They are well developed in the Holly Bank and Baggeridge collieries, on the west side of the coalfield; but in a boring at Claverley the beds approximate the Forest of Wyre type.

The only fossils are the remains of plants, but are not common except in some grey bands occurring near the base in the Oldbury district, and about 180 feet from the summit in a marl-pit near Old Hill Station, where a large and varied flora consists of fifty-eight species of plants that show a mingling of Middle and Upper Coal-measure forms.

The Halesowen Sandstones are confined to the southern

margin of the coalfield, where they are well displayed. They are typically developed in the shafts of Sandwell Park, in the Langley Green Boring, both situated on the east side of the coalfield, and in the Claverley Boring on the west side of the coalfield. Grey sandstones with subordinate bands of grey shales and two or three coals are characteristic of the lower 350 feet of strata. The upper 150 feet consist chiefly of grey shales with a band of blue Spirorbis limestone, comparable in character and position with the Index Limestone of Warwickshire. This limestone occurs in a similar position at Hamstead and Sandwell Park, at Langley Green Boring, at Baggeridge Colliery, and at the Claverley Boring. The basal sandstones around Old Hill and Halesowen somewhat resemble the finer-grained, green Espley Rocks of the Etruria Marls, a resemblance heightened by the occurrence of lenticular beds of conglomerate containing some angular fragments.

At Claverley the flora is represented by several species common to the Newcastle Group of North Staffordshire.

The Keele Group is well developed along the southern margin of the coalfield, and has been proved in borings and sinkings along the east side of the coalfield, but only in a few places on the west side. The Hunnington and Hamstead Beds succeed the Keele Group along the southern margin of the coalfield. They are extremely unfossiliferous, and their relationship to the Keele Group has not been definitely determined, but on the east side of the coalfield they appear to follow conformably on the Keele Group.

Structurally, the South Staffordshire coalfields—'visible' and 'concealed'—are moulded on an anticlinal uplift impressed on the district after the close of the deposition of the Hunnington Beds and previous to the commencement of the Trias. This arch separates the original coal-basin into two troughs: that of the Wolverhampton sub-basin on the west and the Birmingham sub-basin on the east, the denuded arch forming the visible coalfield. The uplift was inaugurated in pre-Carboniferous times, and probably reinstated during the interval between the deposition of the Upper and Lower Carboniferous, but it reached its maximum intensity during a period unrepresented by stratified formations in this country. Earth movements of less intensity followed the same lines subsequent to the latest Triassic sedimentation, and are exemplified by gentle folds and faults and, according to some authorities, by the

igneous intrusions of Rowley Regis, Pouk Hill, and generally over the southern part of the visible coalfield, and in the Wolverhampton sub-basin at Claverley; but no igneous intrusions have been met with in the Birmingham sub-basin.

The complicated structure of the visible coalfield can be referred to two lines of disturbance. The first coincides with the Cambrian outcrop of the Lickey Hills, and northwards runs parallel to the Russell's Hall Fault, and to the general direction of the Dudley and Sedgley anticlinal. The second line forms the axis of the Netherton anticline, and thence runs parallel to the Dudley Port trough-faults to the eastern outcrop of the Silurian ground of Walsall. The main fractures, it will be observed, follow these lines or their north-and-south and east-and-west resultants. Of these resultants, the east-and-west faults, known as the Bentley faults, play an important part in the distribution of the coals. South of the Bentley faults lies the Thick Coal area, largely exploited and of an intricate structure; north of the Bentley faults the Thick Coal is absent, and the structure is much less complicated over Cannock and Cannock Chase.

The Russell's Hall Fault skirts the western margins of the Rowley Regis basalt, and the Silurian uplifts of Dudley and Sedgley. With a throw of over 400 feet down west at Rowley Regis, it brings in the Etruria Marls of Old Hill. The Dudley trough-faults are important by introducing an area of Thick Coal, 390 feet deeper than on either side of the faults. Between Tipton and Darlaston a series of east and west faults have the effect of neutralizing the northerly rise of the measures, thus introducing a large area of Thick Coal.

North of Darlaston the Thick Coal crops out, and is succeeded to the north by lower measures until the Deep or Bottom Coal is at a shallow depth on the upthrow side of the Bentley trough-fault, of which the major fault has a downthrow north of 360 feet. Not only are higher measures introduced, but from this point northwards the general strike of the measures remains approximately north and south, and the Thick Coal is absent or is represented by several separate seams. North of these faults numerous east and west faults traverse the eastern part of the coalfield, and neutralize the general easterly rise of the coals up to a north-and-south fault (Clayhanger Fault) skirting the Silurian inlier of Walsall and bringing in the Etruria Marls of Aldridge. The dip is then to the east, and remains so up to the Eastern Boundary Fault. An east-and-west fault

crosses the coalfield south of Great Wyrley, and is interesting as marking the northernmost occurrence of igneous intrusions. A north-and-south fault, called the Mitre Fault, commencing near Essington, runs northwards past Cheslyn Hay to Cannock, and thence northwards under the Trias of Cannock and Huntington. Its downthrow is to the west, and is sufficiently great to introduce the Etruria Marls of Essington and Cheslyn Hay.

A powerful dislocation (Western Boundary Fault), bringing Trias on the west against Coal-measures on the east, enters the district near Clent, and extends past Stourbridge to Kingswinford and Himley. Between Himley and Wolverhampton the character of the dislocation is not clear, but highly inclined Hunnington Beds are brought close to the Silurian of Sedgley, and a narrow strip of these measures borders the coalfield in which the Baggeridge pits reaching the Thick Coal are situated. At Essington the character of the dislocated ground has been proved in the workings of Holly Bank Colliery, where it is found to consist of three or more dislocations having an aggregate downthrow west of 2,000 feet. The coals are intact between the faults, and the dip gradually decreases westwards. Between Holly Bank and Huntington, the coal-workings, as they proceed west of the Mitre Fault, enter faulted ground apparently of the same character as at Holly Bank. The same kind of faulting occurs at Littleton Colliery near Huntington.

The disturbance along the western side of the coalfield, therefore, consists of a belt of faults, and not of one large downthrow fault, as was previously conjectured.

Crossing to the east side of the coalfield, explorations at Rugeley, at one of the Cannock pits, and at Walsall Wood Colliery entered disturbed ground, those at Walsall Wood proving a belt of faults having an aggregate downthrow east of 1,500 feet. Farther south at Aldridge the disturbed belt is greatly shattered, and the strata are under great tension. South of Aldridge the direction and character of the faulting is not so well known.

The coals are bituminous and suitable for house, manufacturing, and locomotive uses. As house coals, some of the seams of Cannock Chase have a high reputation. These and the Ten Yard or Thick Coal characterize the coalfield. Cannel occurs only in limited quantities. The Thick Coal crops out between Bilston and Darlaston, and, as previously stated, does not occur north of the Bentley faults. South

of the Lye and Halesowen it splits up and deteriorates rapidly, and is at its best around Dudley, where it consists of eight to fourteen beds, resting either directly one upon the other or separated by a thin film. The united thickness of coal occasionally reaches 36 feet; and though individual beds vary in thickness, an aggregate thickness of 30 feet is maintained over a considerable area.

Except in certain water-logged districts, the Thick Coal is now nearly exhausted within the visible coalfield, but its extension into the concealed area is practically untouched except at Sandwell Park and Hamstead on the east.

The Thick Coal presents good examples of rock faults—'swells' and 'rolls'—and, in places, sandstone entirely replaces the seam of coal, and even extends down to the Heathen Coal.

The Brooch Coal, of excellent quality, has an average thickness of 4 feet, and, with the Heathen Coal, is least worked out. North of the Bentley faults the coals between the Deep and the Eight Feet are the most important.

The Eight Feet, known as the Mitre Coal at Essington, is a good house coal. In the Cannock and Cannock Chase area higher seams are workable, but the lower seams remain the most important.

An analysis of the Thick Coal of Hamstead gives: Fixed carbon, 51·56; volatile matter, 35·81; moisture, 11·13; ash, 1·50 per cent. The composition of the Deep Coal of Cannock Chase is shown by the following analysis: Fixed carbon, 52·03; volatile matter, 32·97; sulphur, 0·50; ash, 1·02; water, 13·48 per cent.

The concealed coal areas awaiting development consist of: (1) The partly proved coalfield beneath the Trias of Cannock Chase; (2) the Wolverhampton sub-basin; (3) the Birmingham sub-basin; (4) the Lichfield sub-basin.

(1) Around Cannock the outcrop of the Bunter Sandstone, and whatever Coal-measures lie beneath, are concealed by Drift gravels and sands.

(2) Wolverhampton lies on the eastern margin of a basin filled with Trias. Keuper Marls occupy the centre, from beneath which the inferior members of the Trias rise against Upper Coal-measures in the east along the South Staffordshire Coalfield, and also in the west along the coalfields of Coalbrookdale and the Forest of Wyre. The full thickness of the Triassic rocks has not been penetrated, but doubtless these and the Upper Coal-measures approximate 3,000 feet

towards the centre of the basin. South of the latitude of Wolverhampton the Triassic basin is split into an east and a west portion by an uprise of Coal-measures and Old Red Sandstone along the line of the Trimpley Anticline. The structure of this broad Triassic basin is imperfectly known, and that of the Palæozoic floor on which the Trias rests is scarcely known at all. The anticlinal of Trimpley, however, and the information obtained by boring at Claverley and elsewhere, suggest that the structure of the southern part of the Wolverhampton basin approaches in complexity that of the visible coalfield south of the Bentley faults.

North of the latitude of Wolverhampton the Triassic formation is commonly represented as filling a basin of Coal-measures with the coal-seams stretching unbroken across it. At Holly Bank Colliery, Essington, the Eight Feet Coal, at a depth of 2,400 feet, dips west at 10 degrees on the downthrow side of the last fault proved; on the opposite or Shropshire side of the basin, the Middle Coal-measures dip to the east. The conception of a continuous sheet of productive measures stretching across the basin is, however, somewhat conjectural, and it is possible that the structure of this part of the concealed coalfield is of a more complicated nature.

(3) Birmingham is situated towards the centre of an area beneath which the Thick Coal region of the visible coalfield probably extends. This extension has, in fact, been proved at Sandwell Park and Hamstead collieries.

(4) In the Lichfield area the thickness of the Triassic cover amounts in places to over 1,000 feet. Beneath the cover there is always the possibility of meeting with the pre-Carboniferous platform off which the Coal-measures were denuded before the Trias was laid down. Faults, too, unsuspected in the Trias, may cut out the productive measures or depress them to unworkable depths. On the Warwickshire side of the basin the depth to the Coal-measures is calculable within the outcrop of the Keele Beds west of the Boundary Fault near Tamworth. In the faulted inlier of Hints the depth to the productive Coal-measures is great, possibly approaching 3,000 feet.

CHAPTER XVII

THE FOREST OF WYRE, COALBROOKDALE, AND SHREWSBURY COALFIELDS

RELATIVELY unimportant as a coal-producing region, the coalfield of the Wyre Forest illustrates the filling up with Coal-measures of an irregular pre-Carboniferous hollow. It extends down the Severn Valley from near Bridgnorth to the Abberley Hills; but with an area of about fifty square miles it is estimated to contain only 129,303,705 tons net available supply of coal.

Similar to those of Coalbrookdale, the Coal-measures are separable into an Upper or Sulphur Coal Series and a Lower or Sweet Coal Series. The ascending sequence is measures (thickness not proved); Two Feet (1 foot 1 inch); measures, 17 feet; Four Feet (1 foot 8 inches); measures, 7 feet; Half Yard (6 inches); clunch, 2 inches; coal (1 foot 1 inch); measures, 9 feet; Five Feet (5 feet), forming the top of the Sweet Coal Group; measures, 500 feet; Rider (1 foot 5 inches); measures, 389 feet. The measures are inclined to the east, in which direction they sink beneath the red sandstones and marls of the Keele Group. Thin bands of Spirorbis limestone occur in the Sulphur Coal Group, and on this evidence and on the passage of the group upwards into the Keele Group it has been correlated with the Halesowen Sandstones of South Staffordshire. According to one interpretation, the Etruria (Old Hill) Marls are either represented by the barren measures between the Sulphur Coal Group and Sweet Coal Group, or are absent through unconformity. It is the Sulphur Coal Group that occupies most of the coalfield, and it is only in the central parts (Billingsley and Highley) of the coalfield that the Sweet coals are obtained by pits sunk through the Sulphur Coal Group down to the Sweet coals, which at Kinlet are said to rest directly on Old Red Sandstone.

The Sweet coals furnish a house and manufacturing coal.

The Coal-measures are traversed by dykes and sills of

olivine dolerite that appear at the surface near Kinlet. By some geologists the igneous rock is regarded as a Permian, and by others as a Tertiary intrusion.

Clee Hills.—Coal-measures, resting unconformably on Lower Carboniferous rocks, cover a small area of about four square miles on Titterstone Clee. There are three main seams, with an aggregate of 15 feet of coal, but the seams are variable and locally altered by intrusions of igneous rocks. The productive measures, which contain some beds of red clays, have a coarse conglomerate locally developed near the base, and rest on more steeply inclined Lower Carboniferous rocks, in which subdivision the so-called Millstone Grit must here be included.

A small outlier, about two square miles in area, consisting of Coal-measures containing a few poor seams of coal, caps the Brown Clee Hill to the north of Titterstone Clee. The southern or Titterstone Clee Hill, however, is capped with a sheet of olivine dolerite from 60 to 300 feet thick. On the eastern side of the hill the dolerite reposes on Coal-measures, but on the west side it is underlain immediately by the Old Red Sandstone. The intrusion is certainly post-Coal-measures.

Coalbrookdale Coalfield.

This coalfield extends from Lilleshall, near Newport (Salop) on the north, to the neighbourhood of Linley, about two and a half miles from Broseley, on the south. It covers an area of about eighteen square miles, and is estimated to contain a net available reserve of 153,097,135 tons of coal. The district is famous in the history of the iron trade. Here coal-smelted iron was first successfully produced, and at Ironbridge the first iron-constructed bridge was erected and is still standing.

The Coal-measures are separable into two divisions (1) a Lower Division of grey sandstone and shale, with workable seams of coal and clay-band ironstones; (2) an Upper Division of red and grey marls, grey sandstones, and shales, with thin coals and a band of Spirorbis limestone. Locally, these pass up into Keele Beds, but the junction is generally obscured. The Keele Group is succeeded by red marls and sandstones, with bands of calcareous conglomerates closely resembling the Exhall conglomerate of the Hamstead Group in the Warwickshire Coalfield. The Upper Division appears to occupy a deep and old channel

eroded in the grey productive measures and to overlap them along the southern margin of the coalfield where the Upper Group rests on the edges of the Old Red Sandstone and Silurian rocks. At the Granville pits the

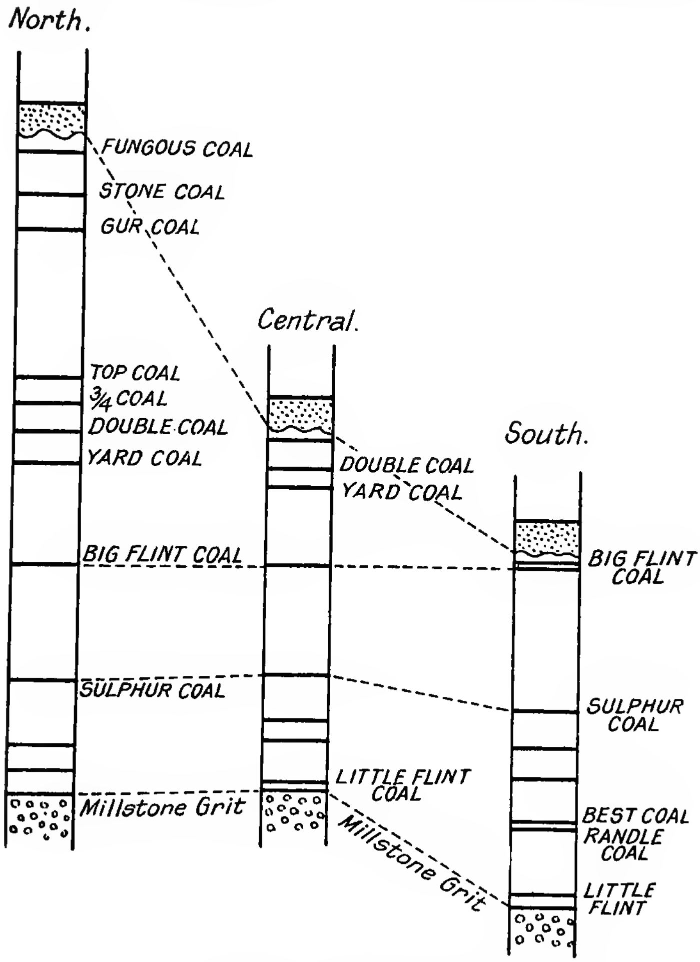


FIG. 43.—SECTIONS, COALBROOKDALE COALFIELD.
Scale, one inch = 100 feet.

Upper measures rest on the horizon of the Fungous Coal; farther south, at Malinslee, they are close to the Double Coal, about 120 feet below the Fungous Coal; and at Broseley, six miles to the south, the barren measures come nearly

down to the horizon of the Big Flint Coal, 40 feet below the Double Coal.

Chief palæontological interest is attached to the Penny or Pennystone ironstone measures, 50 feet below the Big Flint Coal, and about the same distance above the top of the Farewell Rock. These beds are rich in a marine invertebrate fauna, and form a recognizable horizon over the coalfield.

The Coal-measures are inclined as a whole to the east. A fault—Lightmoor Fault—with a downthrow east, divides the coalfield longitudinally into two nearly equal parts. North of Priors Lee this fault is considered to join the Eastern Boundary Fault that for much of its north and south course brings the highest red strata against the productive measures. In the north-west, Coal-measures are faulted against Trias, and on the south they rest on Old Red Sandstone or Silurian.

The chief seams in descending order are Fungous (300 feet above the Farewell Rock), Stone, Gur, Top (4 feet), Half Yard, Double (5 to 6 feet), Yard (2 feet), Big Flint (3 to 4 feet), Sulphur or Stinking (3 to 4 feet), Randle and Clod (4 to 5 feet), Little Flint (1 to 2 feet) resting close on the Farewell Rock (Fig. 43).

The seams produce coking, house, manufacturing, and some steam coals.

Development is taking place under the highest red measures in the direction of Shifnal, which lies on about the same latitude as the Four Ashes Boring to the west of the recent successful explorations at Holly Bank Colliery, north of Wolverhampton.

Shrewsbury Coalfield.

A continuous band of Coal-measures, seven miles in length and one to three in breadth, extends at the foot of the elevated ground west and south of Shrewsbury. A second outcrop of Coal-measures forms an irregular tract at Le Botwood to the north of Church Stretton. The net available supply of coal, including a small amount of the Clee Hills region (p. 222), is estimated at 38,502,859 tons.

In the Shrewsbury Coalfield the Coal-measures, which are of no great thickness, rest along its southern margin on pre-Cambrian and Cambrian rocks. The coal-seams, three in number, with a total thickness of 6 feet, lie towards the bottom of a sequence of grey measures. The seams are impersistent, and are mined to some extent at Hanwood

towards the centre of the basin. A thin band of Spirorbis limestone occurs in the coal-bearing strata. In the northern part of the coalfield the grey measures pass conformably up into red sandstones and red marls, presumably representing the Keele Group of North Staffordshire.

Similar grey Coal-measures are found at the surface near Le Botwood over an area of about three square miles. They rest on Longmyndian rocks on the south, and pass up northwards into red measures resembling the Keele Group. A thin Spirorbis limestone is associated with some thin coals which are not mined. The presence of bands of Spirorbis limestones and the passage into the Keele Group suggests that the Coal-measures of the Shrewsbury and Le Botwood area belong to the Upper Coal-measures, which may have overlapped Middle Coal-measures, and so come to lie directly on older rocks. It is possible, however, that in the south the platform on which the Upper Coal-measures rest was not depressed in the Middle Coal-measure period. The existence of Middle Coal-measures north of the exposed areas is therefore problematical.

CHAPTER XVIII

THE COALFIELDS OF NORTH WALES

THE western rim of the crescent of coalfields surrounding the Cheshire Triassic and Drift-filled plain is occupied by the coalfields of Flintshire and Denbighshire. Coal-measures crop out on the north-eastern bank of the estuary of the Dee in the small coalfield of Neston, thus indicating a connection, under the Trias, of the Flintshire Coalfield with that of Lancashire. Isolated patches of Coal-measures in the Vale of Clwyd and in Anglesea show that the Coal-measures wrapped round the northern flanks of the North Cambrian mountains.

The Coal-measures extend in an uninterrupted tract from the slopes of the Severn Valley, south of Oswestry, to the Point-of-Ayr at the mouth of the estuary of the Dee. The total length of this belt of Coal-measures is 45 miles, with a varying width between the outcrop on the west and the disappearance of the Coal-measures beneath the Trias on the east. Including extensions, the coalfield of Flint embraces an area of 35 square miles, with a reserve of 771,000,000 tons; that of Denbighshire has an area of 47 square miles, with an estimated reserve of 965,000,000 tons.

The Carboniferous succession is complete, and, unlike the Lancashire Coalfield, the highest Coal-measures are at the surface along a great part of the eastern margin. The following table shows the succession:

		Thickness in Feet.
Upper Coal-measures	Erbistock (Keele) Group	2,000
	Coedyrallt (Newcastle) Group -	350–400
	Ruabon (Etruria) Marls	800–900
Middle Coal-measures		1,000–2,000
Lower Coal-measures		0–1,000
Millstone Grit Series		10–700
Carboniferous Limestone		700–2,500
Basement Beds -		0–100
Pre-Carboniferous Rocks		

The Carboniferous rocks rest unconformably on intensely plicated and folded Ordovician and Silurian strata, the basal beds in the north consisting of a red conglomerate. The Carboniferous Limestone, inclined eastwards, dips off the older rocks, but the tectonic structures, so prominent in the older formations, are much less pronounced, though it is considered that the earth movements displayed in the older rocks continued, but in a less degree, throughout Carboniferous times, resulting in a diversity of sedimentary conditions not found in the Carboniferous rocks in other parts of the Midland basin. Thus the Carboniferous Limestone contains thick beds of calcareous sandstone in its upper part, and the Millstone Grits (Cefn-y-fedw Sandstone) consist largely of calcareous sandstone with a brachiopod fauna, as well as beds of chert, as much as 42 feet thick, made up in part of sponge spicules. By some authorities the Millstone Grits and part of the Lower Coal-measures are grouped, on the faunal evidences, with the Lower Carboniferous rocks. No coals occur in the Carboniferous Limestone.

The Lower Coal-measures, made up of a lower part (Hollywell Shales) and an upper sandy series (Gwespyr Sandstone, 200 feet thick), attain their maximum thickness in the north in Flintshire, but die out in the Ruabon-Chirk district. A few coals, a few inches in thickness, occur locally. The lower portion of the Hollywell Shales contains lenticular bands of earthy limestone with *Goniatites* and *Posidoniella*. There is, indeed, little resemblance to the Lower Coal-measures of Lancashire and North Staffordshire, and a closer connection both in lithological type, character of fauna, and absence of coal-seams with the Pendleside Series.

The Great Bala Fault that introduces the Carboniferous Limestone inlier of Hope Mountain divides the North Wales Coalfield into a northern—Flintshire—and a southern—Denbighshire—coalfield. In both, much of the Middle Coal-measures are buried under Drift, so that, as in Lancashire, the character of the strata, sequence of coals, and structure of the two coalfields are obtained for the most part from mining information. As will be seen from the following table, the order of the workable seams of coal and their names change from place to place:

Southern Flintshire.	Denbighshire.	Thickness in Ft.	Ins.
	Measures -	200	0
	Top Droughy Coal	6	6
	Measures	60	0
Measures with thin coals (262 feet)	Cannel Coal	2	6
	Measures	60	0
	Ribbon Coal	1	10
	Measures	60	0
	Lower Droughy Coal	5	0
	Measures	21	0
	Smithy Coal	1	6
	Measures	60	0
	Drowsall Coal	7	6
	Measures	30	0
Powell	Powell Coal	3	3
Measures	Measures	40	0
	Two Yard Coal -	6	9
	Measures	20	0
Hollin Coal	Bench Coal	1	9
Measures	Measures -	30	0
Crank Coal	Crank Coal	1	8
Measures -	Measures	30	0
Brassey Coal	Brassey Coal	5	6
Measures	Measures	60	0
Rough Coal -	Black Bed Coal -	2	3
Measures -	Measures	60	0
Five Yard or Main Coal	Main Coal	11	6
	Measures	30	0
	Brassey Coal	3	0
	Measures	30	0
	Upper Yard Coal	2	0
	Measures	60	0
	Red Coal	2	2
	Measures	30	0
	Stone Coal	2	6
Measures (500) in South Flintshire, with Dirty, Stone, Yard, Cannel, Upper Four Feet, Premier, and Lower Four Feet coals: in North Flintshire, Three Yard, Blue Cannel, Two Yard, Durbog, Five Quarter or Premier, Badger coals—in descending order	Measures	50	0
	Half Yard and Fire-damp Coal	5	5
	Measures	30	0
	Lower Yard Coal	5	0
	Measures	90	0
	Wall and Bench Coal	4	11

The Main Coal is identified throughout Denbighshire and Flintshire, but it is difficult to correlate the seams of northern Flintshire with those of southern Flintshire. In the neighbourhood of Flint an important part of the Coal-measures, including the Main Coal, is replaced by barren red measures resembling the higher group of the Upper Coal-measures.

The intermediate measures consist of shales and sandy shales, with some sandstones, notably the Hollin Rock of Flintshire, from 40 to 200 feet in thickness, above the Hollin Coal. In Denbighshire a sandstone—Cefn Rock—occurs in the upper part of the Middle Coal-measures. In the Ruabon and Chirk district the Middle Coal-measures attain a thickness of nearly 2,000 feet with fourteen workable seams of coal. Around Brymbo, most of the workable seams lie in about 200 feet of measures above the Main Coal, and with a development of sandstone 500 feet above the Main Coal. In the Buckley district the Hollin Rock is succeeded by a series of grey clays, siliceous clunches, and purplish marls, about 100 feet thick, constituting the famous Buckley fireclay group. They crop out only in the Buckley area, but in three belts due to repetition by a series of westerly downthrow faults.

Middle Coal-measures underlie the estuary of the Dee as far east as Queen's Ferry, and crop out under Boulder Clay in the smaller coalfield of Neston on the Cheshire side of the estuary. In ascending order the coals are: Two Feet (2 feet 3 inches), Seven Feet (7 feet 2 inches), Five Feet (5 feet), and the Six Feet which is considered to represent the Rushy Park Mine of the Wigan Coalfield (p. 237).

The Upper Coal-measures, which are exposed in numerous sections, bear a close resemblance both in general character and in many details to the Upper Coal-measures of North and South Staffordshire. The Ruabon Marls, well exposed in the Ceiriog east of Chirk and in large brick-pits around Ruabon, consist of purple and mottled clays with bands of Spirorbis limestone on several horizons. Espley Rocks, of a coarse type, containing large subangular fragments of Cambro-Silurian rocks, are developed near the middle and in the lower part of the sequence.

The Ruabon Marls graduate upwards into grey sandstones and shales, with four coals, one of which—the Morlais Main Coal—consists of 4 feet 9 inches of coal and 1 foot 11 inches of parting. Near the base a thin limestone with *Spirorbis* and *Anthracomya calcifera* accentuates the resemblance to the Newcastle Group of the North Staffordshire Coalfield. The flora also is identical.

The red sandstones and marls succeeding the Coedyrallt grey measures are lithologically similar to the Keele Group, but higher measures—Erbistock red sandstones and conglomerates—which crop out below Overton Bridge are possibly

the equivalent of the Hamstead Beds of the Warwickshire Coalfield. Limestones with *Spirorbis* have not been found, but towards the base the occurrence of *Pecopteris unita* indicates a position in the Coal-measure sequence, and removes the group from the Permian formation in which, until recently, it was included.

The structure of the coalfield is complex. On the whole the measures are sharply inclined to the east or north-east. By a system of faulting trending north-north-west or parallel with the great Vale of Clwyd, conjointly with an east and west set, the coalfield is parcelled out into a series of blocks, rendering mining difficult and expensive. Most conspicuous among the east and west faults are the Bala and Viaduct faults. The Bala Fault, trending east-north-east to west-south-west, enters the Carboniferous tract from the pre-Carboniferous area to the west, and is considered to be the largest fault in Britain. Swerving northwards as it crosses the coalfield, it separates the Denbighshire Coalfield from that of Flintshire. Similarly the nearly east-and-west Viaduct faults along the Dee Valley, south of Ruabon, partition the Denbighshire Coalfield into a southern part and a northern part.

Bituminous coals predominate, but the Main Coal, consisting of top coal (3 feet), furnace coal (3 feet 6 inches), bottom coal (4 feet), was regarded as furnishing a best steam coal, though now largely used as a gas coal. The Yard Coal is a best house coal. A considerable number of the seams furnish gas coal.

Famous among the Flintshire coals is the Cannel Seam of the Leeswood Coalfield. This rich cannel bed, lying about 250 feet below the Main Coal, reaches its maximum development at Leeswood, where it is said to have attained to 4 feet in thickness. Southwards it passes in a short distance into a bituminous coal, and northwards it has not proved workable as cannel for more than four miles. The seam consists of smooth cannel, 7 inches to 2 feet 4 inches; curly cannel, 8 inches to 1 foot 4 inches. The cannel is overlain by an oil shale. This shale and the curly cannel were used chiefly for the manufacture of paraffin oil. Oil was obtained from the smooth cannel, but the greater part was sold for the enrichment of gas before the introduction of the incandescent mantle, which killed the trade.

Analyses of smooth cannel give: Carbon, 79·87; hydrogen, 5·78; oxygen, nitrogen, 8·09; sulphur, 0·57; water, 2·84; ash,

2·85. Curly cannel: Carbon, 77·81; hydrogen, 8·47; oxygen and nitrogen, 6·32; sulphur, 0·71; water, 0·68; ash, 6·01. Oil shale: Carbon, 63·32; hydrogen, 5·28; oxygen and nitrogen, 5·38; sulphur, 0·65; phosphorus, 0·07; water, 2·30; ash, 23·00. Curly cannel produces about 80 gallons of crude oil to the ton, smooth cannel about 35 gallons, and shale about 33 gallons.

Cover and Extension.—Facing the Cheshire Plain with an outcrop of productive measures along its eastern margin, and with a known extension of Middle Coal-measures under the estuary of the Dee into Cheshire, and more or less connecting with the Lancashire Coalfield, extensions of the North Wales Coalfield have been postulated, but the figures given for the depths to the productive measures are admittedly speculative. The cover consists, in descending order, of Glacial Deposits, 0 to 350 feet; Trias up to 3,000 feet; barren Upper Coal-measures up to 3,000 feet. The structure of the basin is unknown. Borings in the Wirral peninsula and bordering the estuary of the Dee show surprisingly different results. At Sealands one boring, half a mile north-east of Ferry Bank Farm, reached the Main Coal at a depth of 376 feet from the surface; while another, less than a mile to the east, failed to reach Middle Coal-measures at a depth of 1,632 feet, having in this locality penetrated 932 feet of Trias, 700 feet of mottled marls with seven bands of limestone, and therefore probably belonging to the Ruabon Clays. A boring at Heswall under 60 feet of Glacial Deposits penetrated the Trias formation consisting of Upper Mottled Sandstone, 108 feet; Pebble Beds, 934 feet; Lower Mottled Sandstone, 1,272 feet, beneath which the Carboniferous rocks were proved for 988 feet. Of the Carboniferous part, the lower was in Millstone Grits containing four thin coals; above these came 275 feet of red barren measures, the position of which in the Carboniferous system is uncertain. Possibly they are red Middle Coal-measures faulted against Lower Coal-measures, or red Upper Coal-measures resting unconformably on Lower Coal-measures. It is certain that the middle productive measures are absent, for the beds below the red series contain numerous marine shells, and in this respect and in lithological character resemble the Hollywell Shales. The estimated reserve is 635,330,217 tons.

CHAPTER XIX

THE LANCASHIRE COALFIELD

THIS coalfield, with an area of 217 square miles of exposed Coal-measures, ranks next in point of size and importance to the Yorkshire Coalfield. Like that of North Staffordshire, it is triangular in shape, with its apex four miles north of Burnley and its base between Stalybridge on the east and Prescot on the west. The available resources of the proved coalfield have been estimated at 4,238,507,727 tons. It contains some of the deepest workings of the British Isles, those of the Pendleton Colliery, near Manchester, reaching a depth of 3,500 feet.

East of Manchester the Lancashire Coalfield extends in a narrow strip southwards past Stockport to Macclesfield, thus connecting with the Cheshire Coalfield. Eastwards the Millstone Grits and Lower Carboniferous rocks rise up into a faulted anticline, which is succeeded on the east by the narrow and parallel north-and-south Goyt Trough, extending seven miles south and east of Macclesfield. This trough encloses isolated basins of Lower Coal-measures of the Lancashire type.

South of the Lancashire Coalfield and over the Cheshire plain there extends a buried coalfield of which the structure and depth are unknown.

The Carboniferous formation here reaches a possible maximum development of 11,000 feet. So far as is known, there is an unbroken upward succession from the Carboniferous Limestone, the whole series being divided in the following manner:

		Thickness in Feet.
Upper Coal-measures	Heaton Park Measures	800 +
	Red and grey marls with Spirorbis limestone (Ardwick Series)	500 +
	Variegated shales down to Openshaw Coal	700
Middle Coal-measures	Upper Productive Measures down to the Bradford Four Feet Coal	800
	Middle Productive Measures down to the Arley Mine Coal	1,600

Lower Coal-measures	Lower Coal-measures and Ganister or Mountain Mines Series down to the Farewell Rock	1,400–2,000
Millstone Grits	Grits and shales with a few thin coals	2,000–5,000
Limestone Shales, Yoredale and Pendleside Series	Shales, thin grits, and thin limestones	1,500–3,500

The Carboniferous formation is generally considered to attain its maximum development in Lancashire. It is

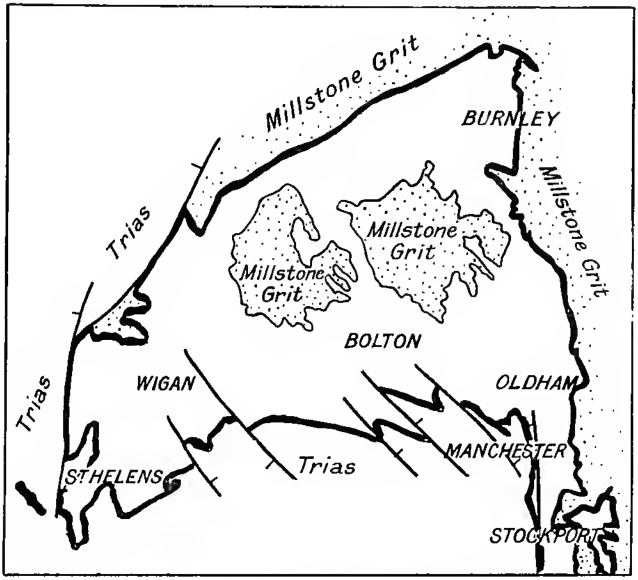


Fig. 44.—Sketch Map of the Lancashire Coalfield.
Scale, one inch = 8 miles.

certainly of great thickness, but if allowance is made for a probable overestimate for the thickness of the Lower Carboniferous rocks, the development is not far in excess of that of Yorkshire.

The Lower Carboniferous rocks and Millstone Grits vary greatly in thickness, but expand northwards, an expansion shared, though in a less degree, by the Coal-measures.

Though the shales of the Yoredales are often of an intense black colour, closely resembling Middle Coal-measures, they do not contain coal, as is shown by the numerous and

fruitless searches along the basin of the Ribble and the Hodder.

The Lancashire and Cheshire coal-basin is bounded on the north, north-west, and east by the Millstone Grits, which also crop out towards the centre of the Lancashire Coalfield, separating the Burnley Coalfield on the north from the South Lancashire basin. Of all the members of the Carboniferous sequence, these are the most variable in thickness and character. In the Burnley district the ascending sequence consists of Kinderscout Grit in two beds of variable thickness, but between 500 to 1,000 feet thick. A thin coal, up to 1 foot 6 inches locally, rests on the highest bed, and has been worked near Belmont. Over this lie the Sabden Shales, 300 to 2,000 feet thick, surmounted by the sandstones and conglomerates of the Third Grit in two, and sometimes in three, beds separated by shales, both members being of variable thickness. The Third Grit is overlain by shales, 150 to 200 feet thick, with thin coals, and locally contains a grit known as the Second Grit or Haslingden Flags. Above this comes the First Grit or Rough Rock, 30 to 80 feet thick, often very soft, and within it, or resting on it, a thin coal known as the 'Sand Rock' or 'Featheredge Coal.' South of Mottram the Millstone Grit Series dwindles down to a thickness of about 1,200 feet, with the Kinderscout Grit represented by two beds known as the Fifth and Fourth grits. The Third Grit persists while the Second dies out, but the First remains as a bed from 30 to 40 feet thick. Of the coals, one between the Third and Second grits, and in the south a thin coal between the Third and First, are the most persistent. They seldom reach a foot in thickness. The Featheredge Coal is generally below workable thickness, but north of Rochdale it consists of 20 to 30 inches of coal of good quality.

The Lower Coal-measures occupy hilly regions. Exposures, therefore, are numerous, both along the margins of the coalfield and bordering the Rossendale Anticline. From the presence in the lower part of two or more workable seams of coal and associated valuable fireclays the subdivision attains more than usual importance, and a reserve approaching 190,000,000 tons of easily-reached coal is attributed to these seams. The succession below the Arley Mine or base of the Middle Coal-measures is as follows:

	Thickness in Feet.
Arley Mine Coal:	
Sandy shales with flagstone (Upper Mottled Flags)	800
Upper Mountain Mine	1–2
Shales with flagstones (Helpet EdgeRock)	200
Black shales with goniatites	5–10
Upper Foot or Bullion Mine	0–1
Black shales	0–20
Lower Mountain or Ganister Mine	1–5
Shales	30
Lower Foot Mine	0–8 ins.
Shales with flagstones (Woodhead Hill Rock) and Salts or Bassey Mine Coal	200

Lower Coal-measures border the Burnley Coalfield, and on the eastern end connect that of Burnley with the South Lancashire Coalfield east of Stockport. They appear at intervals along the west side of the Lancashire Coalfield to near Prescot, and borings through the small inlier at Croxteth Park are considered to penetrate the Lower Coal-measures from about 500 feet below their summit. Strips of Lower Coal-measures are also introduced by faulting within the Millstone Grit area of the Rossendale Anticline.

Above the Upper Mountain Mine the sequence resembles that of North Staffordshire, Derbyshire, and Yorkshire above this horizon, but differs from that on the eastern side of the Pennines by the absence of seams representing the Kilburn Coal of Derbyshire and of the Better Bed, Black Bed, and Beeston coals of Yorkshire. The Mountain Mine coals, so named from their occurrence in hilly regions, are the most persistent. For a considerable distance north-east of Oldham the Lower Mountain Mine and Upper Foot lie about 45 feet apart. They unite about three miles south of Burnley, and continue so throughout this district, forming a seam (Four Feet) of much value. The Lower Mountain Mine and Upper Foot Mine contain calcareous nodules called ‘ coal-balls,’ which inclose well-preserved plant petrifactions. Similar concretions abound in the roof shales of the Upper Foot Mine containing less well-preserved plant remains, but also species of marine shells identical with those found above the Crabtree Coal in North Staffordshire, the Alton Coal of Derbyshire, and the Ganister or Halifax Hard Bed Coal of Yorkshire. The so-called ‘ coal-balls ’ are confined to Lancashire, and are only occasionally met with on the Continent. In Lancashire also they are restricted to these two seams.

The Lower Mountain Mine (Half Yard of Darwen and

Yard of Bacup) and the Upper Mountain Mine (Yard of Darwen) are the chief seams economically, varying in thickness from under 1 foot to as much as 5 feet in the case of the Lower Mountain Mine east of Bacup. The coal produces locally a good coke, but is chiefly got as a manufacturing coal in connection with the associated valuable fireclays. The ganister beneath the Lower Mountain Mine is not constant, and is not of the same quality as the same bed in Yorkshire. At the present day the Mountain Mines are worked around Accrington, Blackburn, Darwen, Bacup, and Wigan for coking, household, and manufacturing purposes.

The Middle Coal-measures, unlike the Lower Coal-measures, occupy low ground that is greatly and thickly overspread with the material left behind by the Irish Sea ice-sheet. Exposures consequently are rare, and the structure and composition of this, the chief part of the coalfield, depend to a great degree on information obtained in mining. This has proved the existence of numerous and powerful faults, breaking up the districts into blocks, and rendering the correlation of the coals an exceptionally difficult task. Excluding the faulted inlier forming the Manchester Coalfield, a coal variously known as the 'Arley,' 'Little Delf,' 'Royley,' or 'Ridacre' Coal, and as the 'Habergham Mine' and 'Marsden Four Feet,' or more generally 'Arley Coal' in the Burnley Coalfield, is universally taken as the base. The Worsley Four Feet Coal or Pendleton Top Four Feet is taken by mining engineers as the base of the Upper Series. Viewing the coalfield as a whole, the Middle Coal-measures occupy three areas: (1) South Lancashire Coalfield, separated from that of Burnley by the Rossendale Anticline; (2) the Burnley Coalfield; (3) the Manchester Coalfield.

1. **The South Lancashire Coalfield.**—The following is the order of the seams, with the thicknesses of the intervening measures given for the Worsley district down to the Trencher Bone Coal, and for the Wigan district between this coal and the Arley Mine:

	Worsley Four Feet,
	Measures 800.
	Binn,
	Measures 80.
Ince and Gidlow Group of Wigan.	Crumbouke,
	Measures 40.
Earth and Potato Delf of St. Helens	Brassey,
	Measures 80.
	Rams,
	Measures 240.

Pemberton Group and Wigan Group	White and Black, Measures 250. Doe, Measures 40. Five Quarters, Measures 240.
Wigan Nine Feet	Trencher Bone, Measures 230. Cannel and King (Upper and Lower Bent of Oldham). Measures 100. Ravin Mine, Measures 80. Yard, Measures 120-300.
Rushey Park of St. Helens	Orrell Five Feet, Measures 180.
Little Delf of St. Helens	Arley, Orrell Four Feet (Royley Mine of Oldham).

Below the Trencher Bone (Wigan Nine Feet and Roger Nine Feet of St. Helens), the Arley and Yard coals have been extensively worked, and to a less degree seams known as the Rushy Park of St. Helens, Three-Quarters, Half Yard, and Plodder of the Worsley district.

In the Wigan district the well-known Wigan Cannel overlies the King Coal, but the cannel is now mainly exhausted. From Wigan as a centre the cannel from a thickness of 3 feet decreases in every direction.

The King Coal, in places with a trace of cannel on the top, has been extensively worked at Stonyclough, Clifton, Ainsworth, Radcliffe, and Elton. It has been correlated with the Upper and Lower Bent seams of Oldham, 700 feet above the Royley Mine at Ashton-under-Lyne.

In the Wigan district the Wigan Nine Feet is succeeded by the Wigan Four Feet and Five Feet coals, and these by the Pemberton Four Feet, Pemberton Two Feet, Pemberton Five Feet coals, distributed among 600 feet of measures, of which nearly one-half separates the Wigan Five Feet from the Pemberton Four Feet. East of Wigan the Pemberton Two Feet and Four Feet unite to form the Great Seven Feet Coal, but are separated at Worsley under the names White and Black coals. The group is known as the Florida Series at Haydock, and the Lower and Higher Main Delf of St. Helens. The Rams Coal is occasionally known as the Seven Feet and the Six Feet.

The Ince Group consists of the Ince Seven Feet and Ince Four Feet. East and north of Oldham, along the outcrop

of the Middle Coal-measures, the coals worked are the Royley, Two Mine, New Mine, Old, and Roger.

In shape the South Lancashire Coalfield is that of a crescent, forming the northern half of the Cheshire basin, towards the centre of which the Lower and Middle Coal-measures are inclined at high angles up to their disappearance under the Permian and Trias. The crescent is bounded on the east by an anticline traversed by the north and south anticlinal fault ; on the north by the Rossendale Anticline, of which the measures are inclined at comparatively gentle angles southwards; and on the west partly by a fractured belt and partly by a fault.

The coalfield is crossed by numerous faults which break the general concentric arrangement of the outcrop of the coals so far as the positions of the outcrops under the nearly universal sheet of Drift can be plotted by projection from depths obtained in mining. The general trend of the faults is from north-west to south-east. Others run east and west, parallel with the Rossendale Anticline.

Of the northerly directed faults that of the Irwell Valley crosses Manchester west of Salford and the Central Stations, and has been estimated to have a throw of over 1,000 yards at its maximum and 400 yards at Manchester.

Farther east the Bradford Fault has been represented as a nearly north and south fault with a vertical displacement of 600 yards.

The greater part of the faulting is of pre-Permian date. The Irwell Valley and Bradford faults introduce the Upper Coal-measures of the Manchester Coalfield between a tract of the Middle Coal-measures on the east and west, very much as the Apedale Fault (p. 166) brings in a prolongation of high Upper Coal-measures towards the centre of the North Staffordshire Coalfield.

Though the Middle Coal-measures contain a rich fossil fauna and flora, sufficient attention has not yet been paid to the faunal distribution for zonal purposes. The roof of the Arley Mine yields *Carbonicola robusta* in the Wigan district, and the same shell occurs 12 feet below the Arley Mine at Chisnall Colliery, and 54 feet below the Three-Quarter Coal at Tydesley. *Carbonicola turgida, C. subrotunda* are recorded from above the Cannel Coal at Hulton. Marine shells—*Ctenodonta, Nuculana, Pseudamusium,* among others—occur 200 feet below the Bradford Four Feet Coal at Ashton-under-Lyne, but have not been recorded in any of the shaft-sinkings.

The coals are bituminous, yielding gas, house, and manufacturing coals. Some of the seams or parts of them yield coke and also coals for steam-raising purposes. The well-known Wigan cannel gives on analysis: Carbon, 80·07; hydrogen, 5·53; oxygen and nitrogen, 16·20; ash, 2·70 per cent.

2. **The Burnley Coalfield.**—This basin of Middle Coal-measures, lying at the apex of the Lancashire Coalfield, is separated from that of South Lancashire by the Millstone Grits of the Rossendale Anticline, but is connected with it on the east and west by the outcrops of the Lower Coal-measures. The Middle Coal-measures occupy an area of 20 square miles. The Arley Mine, also known as the Full-edge Main Coal, forms the base of the Middle Coal-measures; above it lie a little over 1,000 feet of measures with seams representing the Wigan, Pemberton, and Ince groups of coals. The Arley Coal, and the Dandy above it, are worked, but the chief resources of the coalfield lie in the Mountain Mines within the outcrop of the Lower Coal-measures.

3. **The Manchester Coalfield.**—The Upper Coal-measures of this small inlier are penetrated down to the Parker Mine Coal by the shafts of Bradford Colliery.

The Upper Coal-measures are at their maximum development in and around Manchester, but are known to occur in shafts and borings along the southern margins of the South Lancashire Coalfield, though travelling west the Upper Coal-measures are gradually cut out by the overlying unconformable Permian and Trias.

In its course along the southern margin of the coalfield the base of the Upper Series is taken at the Worsley Four Feet or Pemberton Upper Four Feet, but in the Manchester Coalfield doubt has been expressed whether this seam of coal is represented by the Bradford Four Feet or by the Parker Mine Coal 440 yards below the Bradford Four Feet.

As now generally understood, the Upper Series from the Bradford Four Feet upwards consists of (1) the Bradford Series, 330 feet thick, of grey measures, with the Three-Quarters, Two Feet Nine, Charlotte, and Openshaw coals in ascending order; (2) variegated shales, clays, and sandstones, 700 feet thick, resting on the Openshaw Coal; (3) the Ardwick Series, 500 feet thick, consisting of red and purple marls, with twelve bands of limestone, some with *Spirorbis* and *Anthracomya phillipsi*.

Possibly higher beds, though not usually reckoned as higher than the Ardwick Series, occur in the Heaton Park

Boring, in which, under the Permian (Collyhurst Sandstone), there lie 263 feet of red unfossiliferous sandstone and marls resting on 519 feet of grey shales and sandstone, with a thin coal near the top, down to the bottom of the boring. The Heaton Park Section below the Collyhurst Sandstone may represent the Bradford Series and the barren measures under the Ardwick Series, but in this case it is difficult to account for the absence at Heaton Park of a representative of the Bradford Four Feet, which is a constant seam both south and north of the Irwell Valley Fault. The strata between the Bradford Four Feet and the next seam below—the Parker Mine—consist of 440 yards of barren measures, chiefly sandstone. Two readings of this sequence have been put forward—one is that the Parker Mine is the Manchester equivalent of the Worsley Four Feet, another view considers that the barren measures replace the Rams group of coals which should occur at Bradford if the Worsley Four Feet and Bradford Four Feet are identical.

In past years the Ardwick Group was mined for the sake of the limestone. One of these mines gave the following sequence:

	Ft.	*Ins.*
Permian:		
Marl	4	6
Limestone	1	2
Red clay	10	8
Limestone	1	4
Red clay	11	0
Limestone	1	4
Red clay	13	6
Limestone	0	10
Red clay	36	0
Limestone	1	0
Grey and red clays	24	0
Limestone	2	0
Clays	99	0
Limestone	4	0

	Ft.	*Ins.*
Permian:		
Red and green shales	15	0
Limestone	3	0
Red and green clays	4	0
Limestone	1	0
Clays and shales	15	0
Limestone	1	6
Shales and grits with Black Band Ironstone	52	6
Limestone, Main	9	0
Red shale, thin coal	66	6
Shale and Sandstone	81	0
Red shale	15	0
Limestone	2	0
	475	10

The fossil plants of the Bradford Series and Ardwick Beds indicate a high position in the Coal-measures, and a thin limestone with *Spirorbis* and *Anthracomya phillipsi* is recorded from above the Bradford Four Feet Coal. *Anthracomya phillipsi*, *Spirorbis*, *Carbonia*, and fish remains are found in the limestones of the Ardwick Series.

The nearest coalfield to Lancashire giving a complete Coal-measure sequence is that of North Staffordshire, from which it is separated by an outcrop of Lower Carboniferous

rocks and Millstone Grits between Macclesfield and Congleton, a distance of 14 miles. The Lower Coal-measures of both coalfields are similar in character, showing an increase in thickness towards the north-north-east. The fossils above the Crabtree and Lower Mountain Mine are identical. If, then, as has been postulated, a barrier across the Cheshire plain separates the two areas, it is of later growth than the Lower Coal-measures. The Middle Coal-measures of Lancashire thin out in a westerly direction, as they do in North Staffordshire, the general increment being to the north-north-east, as is the case with the Upper Coal-measures of North Staffordshire; but while the Upper Coal-measure sequence of North Staffordshire is known in great detail, that of Lancashire is imperfectly known, and the comparison given below can only be regarded as tentative:

North Staffordshire.	*Feet.*	Lancashire.	*Feet.*
Keele Group	—	Red Measures of Heaton Park -	—
Newcastle Group -	350	Grey Measures of Heaton Park -	519
Etruria Marls	1,100	Ardwick Series -	1,200
Black Band Group (Bassey Mine at base) - -	450	Bradford Series (Bradford Four Feet at base)	330
	1,900		2,049

Cover.—The formations newer than the Carboniferous bordering on the coalfield consist of the Permian and Trias; of the latter, the thickness of the Bunter division only is useful, as the Keuper division occurs over areas beneath which the coals lie at great depths, or of which the structures in the Carboniferous rocks are unknown.

	Feet.
Bunter Sandstone, with pebbles in lower part	1,200
Permian marls and limestones, with marine shells	300
Permian Sandstone (Collyhurst)	1,300

At Openshaw the Permian has a total thickness of 1,322 feet; at Heaton Park, 1,094 feet; at Ardwick, 300 feet; at Patricroft, 92 feet. West of the Manchester district the Permian with some irregularities gradually diminishes in thickness, either by attenuation or by a lateral passage into Bunter, and at St. Helens the Carboniferous rocks are directly succeeded by the lower division of the Bunter formation. The Collyhurst sandstones are capricious in

their occurrence, and appear to fill up hollows in the Carboniferous floor. A large number of characteristic shells have been obtained from the limestones at Fallowfield, proving their correspondence with the Magnesian Limestone Series of the Nottinghamshire and Yorkshire Coalfield.

The Triassic sandstones contain large volumes of water, which pass down into the porous Coal-measure sandstones, especially in the vicinity of faults. For this reason a continuous barrier of coal has been left against the Irwell Valley Fault.

Extensions.—The Coal-measures, when they sink under the covering formations, have a varying but high dip, and this dip, perhaps due to faulting, is steeper to the south than to the north. As over much of the area it is the highest and barren strata of the Coal-measures, of great thickness, that dip under the newer formations which rapidly thicken towards the centre of the Cheshire basin, the workable coals will soon reach a depth exceeding 4,000 feet unless, as has been postulated, the Carboniferous rocks, after descending, turn up to the south. The rapidly increasing depth to the productive measures in the vicinity of the coalfield is a certainty, and any considerable extension of the coalfield farther to the south-west of Manchester is problematical.

Ingleton Coalfield.

At Ingleton, in the north-west corner of the West Riding of Yorkshire, a small area of productive Middle Coal-measures forms an isolated coal-basin that is partly hidden under Permian strata, and for the most part covered by Glacial Drift. It is situated on the south-west or downthrow side of the great Dent or Craven Fault (5,375 feet south-west). The River Greete separates a northern from a southern district in which alone coal-mining on a limited scale has taken place. The Coal-measures consist of an upper series of red sandstones and clays without coal-seams, and of a lower grey series containing two or more workable coals. Near Bentham some seams lying either in the Lower Millstone Grits or upper part of the Carboniferous Limestone Series were worked in the past. The limits of the small basin of Coal-measures are clearly

defined by the Dent Fault on the north-east, and by the outcrops of the Millstone Grits on the north, north-west, and south-east. Owing to its remote position and to the recent discovery of some good and thick seams at the New Ingleton Colliery this little basin attains a local importance.

CHAPTER XX

THE CUMBERLAND COALFIELD

On crossing the Wharfe anticline, the Lower Carboniferous rocks to the north gradually assume different lithological characters. The massive Carboniferous Limestone becomes split up by the intercalation of shales and sandstones; seams of coal make their appearance, increasing in thickness and quality until in Northumberland they become workable.

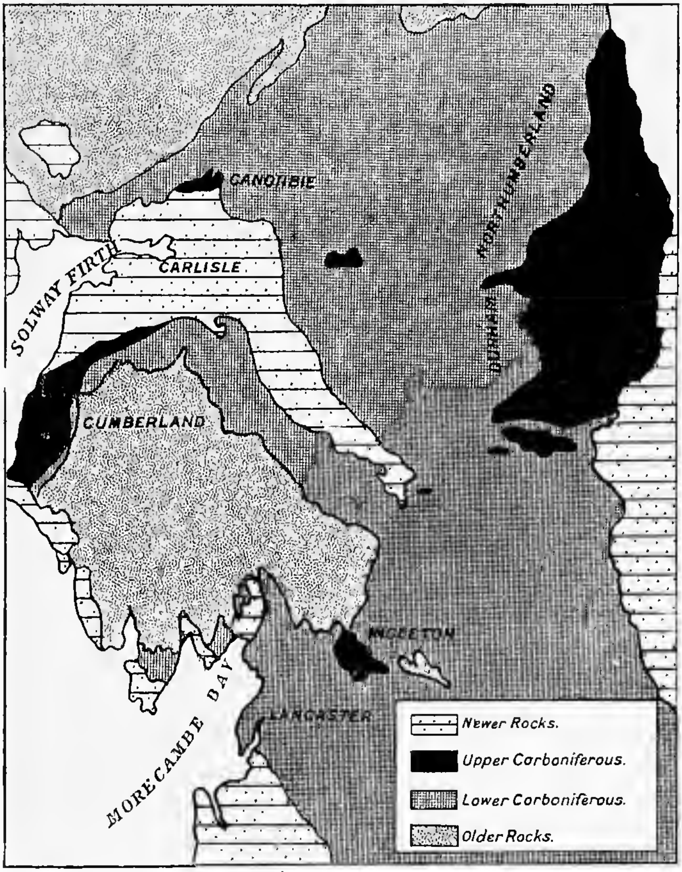
The Limestone Shale, or Pendleside Group, either thins out or, by the development of limestone bands, becomes indistinguishable from the Carboniferous Limestone Series, and, under the name of 'Yoredale Group,' has been placed with this series.

The Pennine uplift extends northwards across the Wharfe anticline, and continues to be the dominant structural feature separating the Northumberland and Durham coalfields on the east from that of Cumberland on the west. Crossing the border, a broad, indented belt of pre-Carboniferous formations separates the Scotch from the English coalfields.

Igneous rocks, contemporaneous with or intrusive into the Coal-measures, rare or absent in the Southern and Midland Provinces, are of frequent occurrence in the northern coalfields, but do not seriously interfere with coal-mining south of the Scottish border.

Separated by a broad tract of Lower Carboniferous rocks and of the older Palæozoic formations of Lakeland from the Lancashire Coalfield, and from the Durham Coalfield by the Pennine uplift, the Cumberland Carboniferous sequence nevertheless forms a connecting link between the Midland and Northern Provinces. The Lower Carboniferous rocks of Cumberland contain several thin, though unworkable, seams of coal; while the Upper Coal-measures of the Carlisle basin resemble those of the type region in North Staffordshire.

The coalfield consists of three districts: (1) An exposed area of 90 square miles stretching from one mile south of Whitehaven, thence northwards through Workington to Maryport, whence a narrow strip extends to the north-east past Aspatria towards Wigton. (2) An undersea area, at



1 inch = about 25 miles.

FIG. 45.—THE COALFIELDS OF NORTHERN ENGLAND.

present worked for a distance of four miles. (3) An area south of Maryport; and another north of Aspatria, covered with Trias, extending across the Carlisle basin to the exposed Coal-measures of the Canonbie Coalfield. The total available coal, including the somewhat problematical amount under the Carlisle basin, is estimated at 1,527,708,805 tons.

The Carboniferous Limestone, rich in hæmatite and with a few thin coals, is succeeded by the Millstone Grits, and these by the Coal-measures which give the following descending sequence:

Whitehaven Sandstone Series	Sandstones and shales with Spirorbis limestone. Sandstones and shales with many plant remains.
Productive Series	Measures with chief coals, base the Main Band Coal. Measures with inferior coals.

On plant evidence the entire sequence has been correlated with the Middle Coal-measures of the Midland Province, though an unconformity is claimed to separate the Whitehaven Sandstone Series from the Productive Series. The break, if any, is slight, and has been based on the same kind of evidence as the alleged unconformity of the Rotherham Red Rock (p. 184) in the Yorkshire Coalfield. In the Productive Series the chief seams in ascending order at Cleator Moor are Yard, Main Band, Bannock Band, Five Feet, Four Feet, Six Feet. At Maryport the seams are Metal and Cannel Band (Main Band in two parts), Crow Band, Rattler Band, Ten Quarters, White Metal Band, Hamilton. Many of the seams show a tendency to split eastward. Thus the Main Band, 10 feet thick in the west, becomes unworkable at Aspatria; on the other hand, the Yard Coal, poor in the west, increases east to 5 feet of good coal.

Palæontological interest is centred in the evidence of age as determined by the plants. The flora of the measures above the Main Band Coal consists of *Calamites varians, C. suckowi, C. cisti, Calamocladus equisetiformis, Sphenophyllum cuneifolium, Lepidodendron wortheni, Sigillaria lævigata, Bothrodendron minutifolium, Zeilleria delicatula, Sphenopteris obtusiloba, S. furcata, Mariopteris muricata, M. latifolia, Neuropteris heterophylla, N. tenuifolia, N. gigantea, Alethopteris decurrens, Cordaites principalis.* The lower part of the Whitehaven Series contains *Calamites approximatus, C. varians, C. suckowi, C. cisti, Calamocladus equisetiformis, Annularia sphenophylloides, Sphenophyllum cuneifolium, Lepidodendron aculeatum, Sigillaria scutellata, S. ovata, S. lævigata, Sphenopteris obtusiloba, Neuropteris tenuifolia, N. scheuchzeri, Alethopteris serli, Cordaites principalis.* In both, the assemblage indicates a Middle Coal-

measure flora. The occurrence of *Lepidodendron wortheni, Sigillaria lævigata*, and *Neuropteris tenuifolia* precludes the upper part of the Productive Measures from the Lower Coal-measures, and *Zeilleria delicatula* is a distinctive Middle Coal-measure species. The absence of fern-like plants, together with the presence of *Sigillaria ovata*, in the Whitehaven Series is also indicative of Middle Coal-measures.

The Carboniferous rocks dip to the west and north-west. Numerous faults, with throws of 300 to 600 feet, and trending north-west to south-east, cross the coalfield, and while dislocating the Coal-measures, pass under the undisturbed Permian sandstones and marls in the southern part of the coalfield.

Most of the coals are bituminous, suitable for household, steam, and gas purposes.

Extensions of the coalfield may be looked for seawards, beneath the Secondary formations of the Carlisle basin, and to a small extent under the Trias south of Whitehaven. Evidence for an extension north and north-west of Aspatria is limited to a few borings and explorations on the downthrow side of a faulted belt bordering the exposed coalfield. In these explorations difficulties are encountered in distinguishing the age of red unfossiliferous sandstones and marls. It is often impossible to decide when a boring, commencing in undoubted Trias, enters red beds of lower Trias, Permian, or Carboniferous age.

Cover.—The Triassic and Permian strata of the Carlisle basin are of unproved thickness. Glacial deposits cover up much of the coalfield and the area to the north.

Canonbie Coalfield.—In Liddle Water, on the Scotch border north of Carlisle, a small patch of Coal-measures appears at the surface from under the Triassic deposits of the Carlisle basin, and for many years coal has been obtained by the Canonbie Colliery. The area of exposed productive measures amounts to about 1½ square miles. It is bounded on the south and south-east by a large fault of over 100 feet downthrow, and on the north-east by an upthrow fault bringing up Millstone Grits. The local succession of the Carboniferous rocks above the Gilnockie Limestone (Eelwell of Northumberland, Hurlet of Scotland) is: Strata with Kilnholm coals, 400 feet; Upper Limestone Group, 500 feet; Millstone Grits, 400 feet; Lower Coal-measures with Rowanburn coals, 450 feet; partly proved Middle Coal-measures

with Byreburn coals; Upper Coal-measures consisting of red sandstones and shales with thin coals near their base, 1,500 feet. On evidence afforded by the fossil flora the red measures above the Byreburn Group of coals have been compared with the upper part (Keele Group) of the North Staffordshire sequence of Upper Coal-measures. In ascending order the chief Rowanburn coals are: Seven Feet, 6 feet; Black Top, 4 feet 9 inches; Five Feet, 5 feet; Three Feet, 3 feet 6 inches; Splint or Nine Feet, 9 feet; Main Coal, 6 feet. Of these, the Seven Feet, Black Top, and Five Feet are worked. The seams of the Byreburn Group range from 3 to 5 feet in thickness.

Estimates of reserves for the concealed areas have been placed as high as 150,000,000 tons on evidence admittedly slight. It is also agreed that most of the seams lie at great depths.

The cover of the Carlisle basin consists of: Glacial deposits, from 0 to 186 feet; Trias, 1,000 feet; Upper Barren Coal-measures, over 1,500 feet.

CHAPTER XXI

THE COALFIELDS OF DURHAM AND NORTHUMBERLAND

COAL-BEARING rocks of Carboniferous age occupy a great part of Northumberland and County Durham, and continue seawards to the east. Formations older than the Carboniferous are confined to the region of the Cheviots, and, though Glacial Deposits obscure much of the outcrop of the Carboniferous rocks, they are covered by formations later than the Carboniferous only along the coastal regions and in the south-east of County Durham.

By far the greatest quantity of coal is obtained from the Coal-measures which occur within a triangular-shaped area, 200 square miles in extent, having its apex near the mouth of the Coquet and its base between Hartlepool and Middleton-on-Tees. The coal-bearing Lower Carboniferous rocks, entering at Berwick-on-Tweed, extend southwards into Yorkshire and westwards into Cumberland, thus covering an area of about 1,500 square miles. The annual output of coal from these rocks, however, is under 500,000 tons, whereas that from the Coal-measures amounts to 40,000,000 tons per annum.

The net available reserves are distributed as follows: for Northumberland Coal-measures, 2,421,996,845 tons; Mountain Limestone (proved), 145,926,836 tons; Mountain Limestone (unproved), 1,828,791,668 tons; undersea coal, 1,112,910,292 tons; for County Durham, including undersea coal (870,028,611 tons), the reserves in the Coal-measures are estimated at 5,271,116,346 tons.

The simple succession of a mass of limestone several thousands of feet in thickness, succeeded by shales and thin grits (Pendleside Series or Upper Limestone Shales), forming the Lower Carboniferous rocks of Derbyshire and North Staffordshire, is replaced in North Yorkshire by an alternating series of limestone, shales, and sandstones termed the Carboniferous Limestone Series and Yoredale Rocks. With

the introduction of arenaceous and argillaceous intercalations coals make their appearance—at first in North Yorkshire as impersistent beds of small commercial value, but gradually increasing in number and importance as the Carboniferous Limestone Series is followed from Yorkshire into County Durham, and thence northwards into Northumberland.

In Yorkshire the limestone beds occur in the following ascending order: Great Scar (600 feet), Hardraw Scar (30 to 40 feet), Simonstone (25 to 30 feet), Middle Limestone (15 to 20 feet), Fourth Set (10 to 20 feet), Third Set (20 feet), Undersett (20 to 30 feet), Main (50 to 60 feet). The limestones are separated by shales and sandstones from 30 to 200 feet in thickness. With a varying thickness of shales developed between the Main Limestone and Millstone Grits, the total thickness on Ingleborough Hill amounts to 1,500 feet. A coal 4 feet thick, lying between the Main Limestone and Millstone Grits, is worked at Winston and Little Newsham in Teesdale. Thinner seams are associated with the Undersett and Main limestones, and are worked locally. A seam near the Great Scar was formerly much raised for coke on Nateby Common. The Tanhill Coal, widely wrought for local supplies in Upper Swaledale and Upper Wensleydale, lies near the base of the Millstone Grits.

In West Durham and South-West Northumberland the Limestone Series maintains the same characters, but the limestones are known under different names. Commencing with the lowest, these are: Melmerby Scar (Great Scar), Jew (Hardraw Scar), Tyne Bottom (Simonstone), Scar, Cockleshell, and Single Post (Middle), Five Yards (Fourth), Three Yards (Third), Four Fathoms (Undersett), Great (Main), Fell Top, and Little limestones.

The intercalated beds consist of sandstones (locally called 'Post'), and shales (locally called 'Metal' in coal districts and 'Plate' in lead-mining districts). Many of the coals are without associated fireclays. In Upper Teesdale thin coals are associated with the Fell Top, Little, Great, Four Fathoms, Three Yards, Five Yards, Scar, and Tyne Bottom limestones. The coal below the Little Limestone is thickest (2 feet). In Weardale the coals are sulphury and of no commercial value. In the Alston district the Little Limestone Coal, sometimes 5 feet thick, lies below the Little Limestone.

Besides coals, the Carboniferous Limestone Series carries lead in Teesdale and Weardale, and the more siliceous varieties of 'Post' are much sought after for silica bricks in

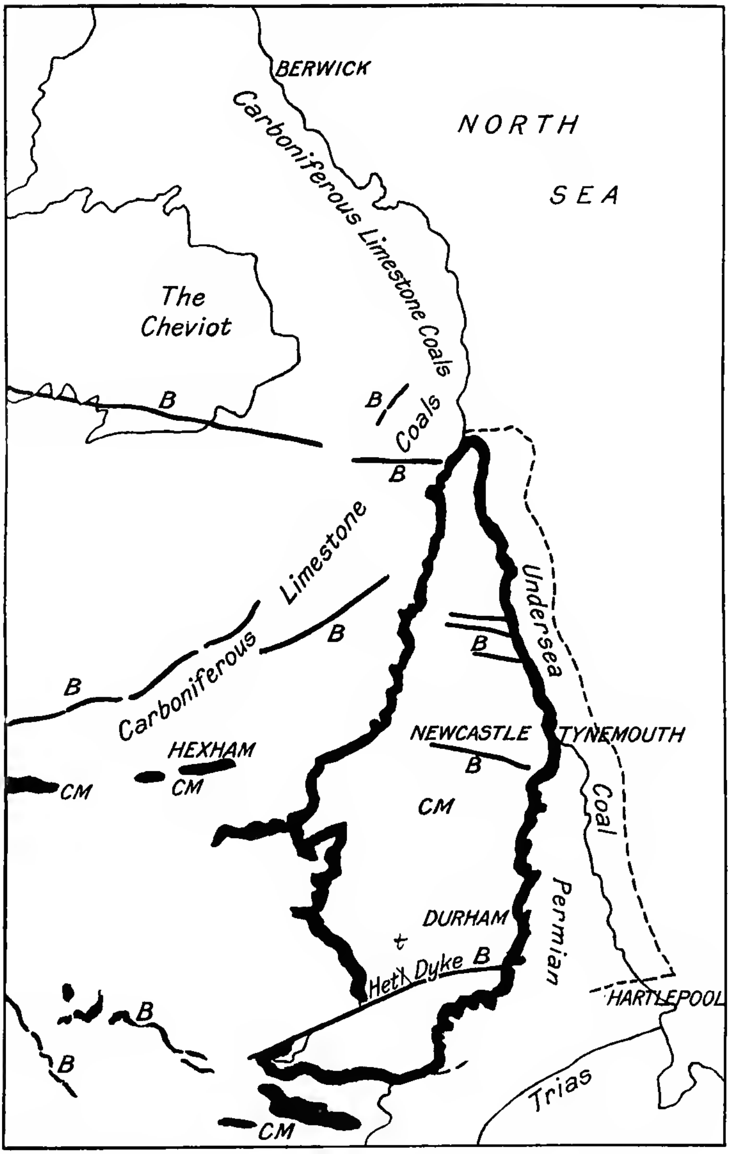


FIG. 46.—SKETCH MAP OF THE DURHAM-NORTHUMBERLAND COALFIELD.

Igneous rocks lettered B; Coal-measures lettered CM.
Scale, one inch = 15 miles.

the Hexham district and at Middleton-on-Tees, in association with the Fell Top, Main, Undersett or Four Fathoms, Three Yard, Two Yard, and between the Five Yard and Scar in Lunedale.

In Teesdale and Alston the thickness of strata between the Melmerby Scar Limestone and the Fell Top amounts to about 1,500 feet; the beds below attain a thickness of 300 feet in Teesdale, and thicken northwards to 1,000 feet at Alston, where thin coals appear. The thickening of the Lower Carboniferous rocks increases north of the Tyne, and the associated coals above and on the horizon of the Melmerby Scar Limestone assume commercial importance.

The Limestone Series has been divided as follows:

		Thickness in Feet.
Bernician	Upper Bernician (Calcareous Group): Sandstones and shales, marine limestones, coals. Base is the Dun Limestone	1,600–4,000
	Lower Bernician (Carbonaceous Group): Sandstones and shales, thin calcareous beds, many coals	800–1,500
Tuedian	Fell Sandstones. Thick sandstones and shales	600–2,000
	Cementstone Group: Shales and sandstones, cementstones and dolomitic limestones	500–3,000

This is the dominant rock formation of Northumberland. The beds follow the Pennine axis of the Cheviot Hills; thus the lowest lie in the west and the higher divisions in the east, sweeping in parallel belts around the complex Old Red Sandstone massif of the Cheviots. The general easterly dip is broken by faulting arranged in a half-circular zone around the Cheviot massif, and by folding. Conspicuous folds are the Corbridge anticline along the north Tyne, the Lowick syncline, and the Holburn-Chillingham anticline. Of the many igneous intrusions, that of the Great Whin Sill, stretching from the Farne Islands southwards to Burton Fell, a distance of eighty miles, is the best known. This intrusive sheet of dolerite or diabase, averaging 80 to 100 feet in thickness, but sometimes diminishing to less than 20 feet, though often parallel to the bedding, cuts across it from an horizon 1,000 feet below the Great Limestone to one 800 feet above it. The rock consists essentially of plagioclase, augite, and titaniferous magnetic iron-ore. An ophitic intergrowth of augite and felspar is observable; micropegmatite plays the part of ground mass between the interstices of the lath-shaped felspars.

No coals of economic value occur in the Tuedian. In the Lower Bernician rocks, coal-seams, of which several are of commercial importance, occur throughout the series. Geographically, the coals form a southern or Plashetts Group and a northern or Scremerston Group. The Plashetts Group consists of sandstones and shales with thin marine limestones in the south, passing northwards into earthy limestones and calcareous grits. In the North Tyne Valley the group attains a thickness of 2,500 feet. The coals, in ascending order, are: Lewisburn, Splint, Shilburnhaugh, Greeneyes, and Plashetts, of which the Plashetts Seam, 4 feet 6 inches thick, is the most important. It is of good quality, coking, and yielding a little ash of a lightish colour; mainly a house coal, it is also used in the manufacture of gas. The sulphur content (2·34 per cent.) is high.

The Scremerston Group consists of sandstones and shales 600 to 1,000 feet thick, with the following seams in ascending order: Wester (3 feet), Cooper Eye (2 to 4 feet), Three-Quarters (2 to 3 feet), Bulman or Main (2 to 6 feet), Scremerston Main or Blackhill (2 to 4 feet), Fawcett or Caldside (2 to 3 feet), and Dun Limestone Coal (1 to 1 foot 6 inches). The Cooper Eye Coal is a good house and steam coal, giving a red ash and yielding an average section of: Coal, 1 foot 7 inches; band, 6 inches; coal, 1 foot 3 inches. The Scremerston Main Coal is of excellent quality, but divided by several partings. It usually has a thin limestone roof.

In the Upper Bernician, the equivalent of the Yoredale Group of North Yorkshire, bands of limestone are numerous, which serve as guides to the various seams of coal, as shown in the table on p. 254.

Over the central area the group is said to attain a thickness of 4,000 feet, but thins away north and south to about 1,600 feet. Among the important seams are included the Fourlaws, Shilbottle, and those between the Little Limestone and Great Limestone. The Shilbottle Coal is of excellent quality, clean, slow-burning, and leaving little ash. The Lickar Group of coals and those below the Little Limestone have been more extensively worked than the others. They yield good coke.

Analysis of the Little Limestone Coal shows: Carbon, 76·81; hydrogen, 5·30; oxygen, 7·44; nitrogen, 1·63; sulphur, 2·02; ash, 4·70; water, 2·003, coke, 64·5; volatile matter, 35·5.

In 1910 the Lower Bernician yielded 121,186 tons of coal,

and in the same year 336,394 tons were obtained from the Upper Bernician.

The limestones are all of marine though shallow water origin, containing thin bands of calcareous shale, and varying in thickness from 10 to 50 feet. Many of them are very fossiliferous, containing a fauna closely agreeing with

Northern.	*Central.*	*Southern.*
	Fell Top.	Fell Top.
	Coal (1 to 3 feet).	Coal, thin.
		Robsheugh.
		Coal, thin.
	Stanton.	Thornbrough.
	Coal (1 to 3 feet).	Coal, thin.
	Netherwitton.	Corbridge.
	Coal (1 to 2 feet).	Oakwood or Clarewood (1 foot to 1 foot 6 inches).
Lickar.	Little.	Little.
Lickar coals.	Coal (1 to 2 feet).	Coal (1 to 5 feet).
Dryburn.	Great.	Great.
Coal, thin.	Townhead or Kiln (2 to 3 feet).	Coal (1 to 2 feet).
Lowdean.	Eight Yards.	Four Fathoms.
Coal, thin.	Coal.	Coal.
Acre.	Six Yards.	Three Yards.
Coal (2 to 4 feet).	Shilbottle (2 to 3 feet).	Coal, thin.
Eelwell.	Nine Yards.	Five Yards.
Coal (2 to 5 feet).	Coal (2 to 4 feet).	Coal, thin.
		Scar.
		Coal, thin.
		Cockle-shell.
		Coal, thin.
		Single Post.
		Coal, thin.
Oxford.		Tyne Bottom.
Oxford coals.		Coal (2 to 4 feet).
		Fourlaws.
Woodend.	Hobberlaw.	Redesdale.
Howgate and Woodend coals.		
Dun.	Dun.	

that of the *Dibunophyllum* zone, the highest palæontological division of the Carboniferous Limestone Series of the Bristol area. The faunal succession has been found capable of separation into horizons by means of the corals and brachiopods, and these again into groups characterized by the presence or abundance of a particular form or forms. The shale and ironstones below the Redesdale Limestone of Redesdale contain a rich lamellibranch and brachiopod fauna of a shallow water facies. Though corals are rare,

Dibunophyllum occurs, and the horizon corresponds in position to the concretionary beds immediately below D 1 of the Avonian sequence. The *Dibunophyllum* zones, D 1, D 2, D 2-3, are well represented. In the higher limestones the tendency of the Dibunophyllids towards Aspidophylloid structure becomes very marked in the Thornbrough Limestone at Gallowhill. In the Fell Top Limestone *Dibunophyllum muirheadi* and *Phillipsastrea radiata* are plentiful, and also latissimoid *Producti* and their varieties. The Four Fathom Limestone is characterized by the abundance of *Saccamina carteri*, but which is also present in a band in the Six Yards and Acre limestones. *Girvanella* is found encrusting corals and encrinital limestones, especially in the highly encrinital Oxford Limestone.

Above the Fell Top Limestone a considerable thickness of barren sandstones and shales intervenes between the Carboniferous Limestone Series and the Lower Coal-measures. These have been correlated with the Millstone Grit Series of Yorkshire. The series varies in thickness from 120 to nearly 600 feet, and with the overlying Lower Coal-measures form the western and southern limits of the great Durham and Northumberland coalfield.

The Lower Coal-measures or Ganister Series, 120 to 300 feet thick, contain a few thin but workable coals (Victoria and Marshall Green coals) from 2 to 3 feet in thickness around Crook, County Durham; and at Eltringham, near Prudhoe, a local cannel, 0 to 2 feet thick, has been worked about 60 feet below the Brockwell Seam. A thin coal and cannel occurs in about the same position in the outliers of Stublick, Plainmeller, Coan-

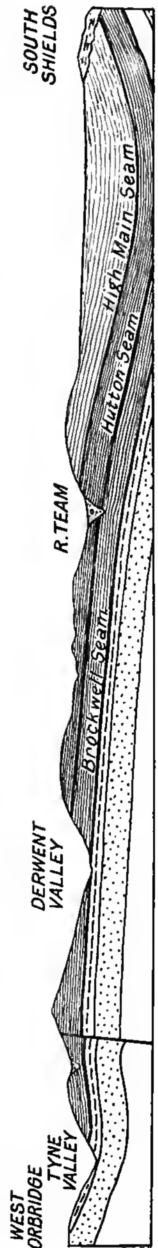


Fig. 47.—Sections across the Southern Part of the Durham Coalfield. (About 22 miles east to west.)

wood, and Midgeholm on the downthrow side of the Stublick Dyke Fault (p. 257).

The Productive Coal-measures, 1,400 to 1,800 feet thick, frequently termed the 'true Coal-measures,' commencing with the Brockwell or Denton Low Main Coal, consist of alternations of sandstones, shales, fireclays ('seggars'), with sixty seams of coal, of which twenty-three are considered workable. Unlike the coals of the Lower Carboniferous rocks, many of the seams rest on beds of valuable fireclays extensively used for firebricks. Beds of fine-grained, hard sandstone, termed 'grindstone post,' come in above the High Main Coal, and were formerly used for making the well-known Newcastle grindstones. The chief beds are known as the 'High Main Post,' 'Seventy Fathom Post,' and 'Grindstone Post.'

The Coal-measures are particularly rich in fossil plants.

Animal remains are not rare, but the coalfield has not been systematically zoned. Distinctive fossil horizons appear to be: (1) A band with *Carbonicola robusta* in the roof of the Brockwell Seam; (2) a marine bed with Cephalopods, 880 feet below the Hutton Seam; (3) a marine bed with Brachiopods, 17 feet above the Five-Quarter Coal; (4) the zone of *Anthracomya phillipsi* in the highest visible Coal-measures that outcrop, 1,700 feet above the Hutton Coal, in the banks of the Wear opposite Claxheugh, near Hylton.

Fossil evidence so slight does not justify a correlation of the Coal-measures with those of the Midland Province, from which they are separated by the concealed barrier of the North Riding of Yorkshire and the Silurian inlier of Malham. From the Scotch coalfields also, with which the sequence is allied, a broad belt of older rock intervenes. The Millstone Grits and Lower Coal-measures may represent the Roslin Sandstone or Moor Rock of the Midlothian Coalfield, but the palæontological break found in that series has not been detected in Northumberland and Durham, neither have the high red measures of Dalkeith and the Glasgow basin been met with.

The structure of the coalfield is that of an irregular basin having its axis directed north and south. The strata rise at a general uniform rate to the north-west, but flatten out eastwards, and in some cases rise eastwards. Near Middleton in Teesdale, the strike is east and west, the Lower Coal-

measures and Millstone Grits here forming the southern margin of the basin up to its disappearance beneath the Magnesian Limestone. Numerous igneous dykes and normal faults, trending a few points north or south of east, cross the coalfield. The best known of the igneous intrusions are—from south to north, Cockfield Dyke, Hett Whin Dyke, Coaley Hill Dyke, Mausoleum Dyke, and the Acklington Dyke, which stretches from the coast near Acklington across Northumberland and the Cheviots into Scotland. In the vicinity of the intrusions the seams are frequently reduced to cinder and sooty substances. The dykes vary in width from 1 to 60 feet. The chief faults are the Butterknowle in South Durham, with an upthrow north of 240 to 420 feet; the Ninety Fathoms, with a downthrow north of 750 feet at Kenton, 1,000 feet at Gosforth, 900 feet at Earsdon, and 600 feet at Whitley. The Stublick, commencing to the north of, and running parallel with, the Ninety Fathoms Dyke as it dies out westward, is continued across the Lower Carboniferous outcrop. It has a large downthrow north, and introduces into the heart of the limestone country the small isolated coalfields of Stublick, Coanwood, and Plainmellor.

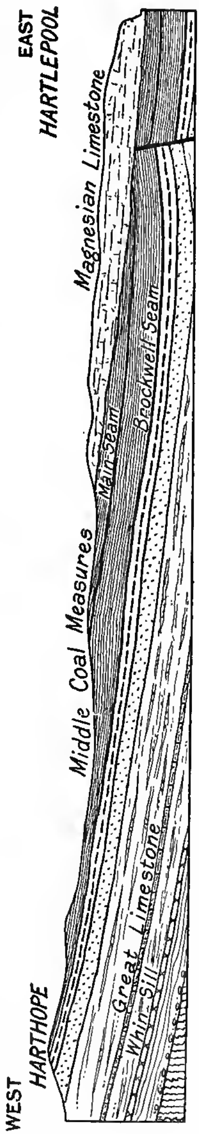


FIG. 48.—SECTION ACROSS THE NORTHERN PART OF THE DURHAM COALFIELD (about 22 miles, east to west).

The correlation of the workable seams is attended with much difficulty, since not only does the same seam receive different names, but the same name is applied to quite different seams. The descending order of the coals and the thickness of measures between them, according to one scheme, is as follows:

Seam.	*Characteristics.*	*Thickness in Feet.*
Closing Hill	Local development	$1\frac{2}{3}$
	Measures	450
Hebburn Fell	Local	$2\frac{2}{3}$
	Measures	250
Five-Quarter	Local	4
	Measures	260
Three-Quarter, Black Close	Variable	2
Moorland, Splint, Crow	Measures	50–180
High Main, Shield Row	The original Wallsend, split up in Durham	6–7
	Measures	50–150
Metal and Stone	Separate in Northumberland, united in Durham	3–6
	Measures	60–110
Yard	Constant in Northumberland, Main of Durham	2–6
	Measures	60–100
Maudlin	Maudlin of Durham, Bensham of Northumberland	2–6
	Measures	75
Six-Quarter and Five-Quarter	Unite to form Hutton of Consett	$2\frac{2}{3}$–$3\frac{2}{3}$
	Measures (with Brass Thill)	50
Hutton	Hutton of Durham, Low Main of Northumberland	2–6
	Measures	30–100
Plessy	Local in Northumberland	2–3
	Measures	80–180
Little Wonder	Local in Northumberland	Thin
Harvey	Harvey in Durham, Beaumont of Northumberland	3–4
Hodge	Local in Northumberland	$2\frac{1}{2}$
	Measures	20
Tilley	Local in Northumberland	2
	Measures	30–45
Hand and Stone	Ryton area	Thin
	Measures	25
Five-Quarter, Six-Quarter	Unites with Stone to form the Busty of Durham	$3\frac{1}{2}$–6
	Measures	30–50
Three-Quarter, Yard	Yard of Wylam	$3\frac{1}{4}$
	Measures	50
Brockwell	Persistent	—

This list is not complete, and several seams given in the Home Office list are omitted. Among the chief seams are the Brockwell, Three-Quarter, Five-Quarter, Low Main or Hutton, Bensham, and Maudlin. The Hutton or Low Main is the best gas and house coal in Durham, but north of the Tyne becomes a steam coal. The High Main of South Northumberland is nearly exhausted. It was the Wallsend Coal as applied to house coals. It splits up

southwards and becomes the Shield Row Coal of Durham.

The coals are of a bituminous character, those of Durham yielding the best coking and gas coals in the kingdom. These have much the same chemical characters as the house coals of the district, the difference in their commercial value apparently depending on the physical and textural features.

Some analyses of Northumberland and Durham coals are: Brockwell—Carbon, 81·93; hydrogen, 4·85; oxygen, 6·47; nitrogen, 0·69; sulphur, 0·65; ash, 3·86; water, 1·55; Beaumont, house coal—Carbon, 84·50; hydrogen, 5·15; nitrogen, 1·43; oxygen, 6·93; sulphur, 0·63; ash, 1·36; Hutton, gas coal—Carbon, 80·51; hydrogen, 4·80; oxygen, 6·82; nitrogen, 1·44; sulphur, 2·07; ash, 3·00; water, 1·36.

Cover.—South of Tynemouth the Coal-measures disappear beneath the Magnesian Limestone Series. The two formations are quite discordant, and it is evident that the earth movements affecting the older strata were almost completed in pre-Permian times. Thus the Ninety Fathom Dyke possesses a throw of only a few feet in the Magnesian Limestone. This formation consists of an upper group of limestone, 500 to 650 feet thick, and a lower group of shales (Marl Slates), 3 to 15 feet thick, resting on yellow sands from 0 to 104 feet thick. At Hartlepool it is considered that much of the Magnesian Limestone is represented by a bed of gypsum and anhydrite 265 feet thick. East of a line drawn from West Hartlepool to Darlington the Triassic sandstones reach a thickness of 1,000 feet, and are underlain by 300 feet of saliferous marls containing beds of gypsum and rock salt. Considerable areas of the coalfield are thickly covered with glacial deposits, which frequently fill and conceal pre-glacial hollows and valleys, sometimes to a depth of over 300 feet, as in the case of the well-known Teamwash. The bottom of this valley is 140 feet below sea-level (Fig. 47, p. 253). The glacial material consists of a lower Boulder-clay and an overlying series of sands and gravel and laminated clays. Besides the buried valley of the Tyne, another old channel follows the present course of the Wear to Durham, running thence past Chester-le-Street to near Newcastle, where it joins the Teamwash.

CHAPTER XXII

THE COALFIELDS OF SCOTLAND

Between the Highlands of Scotland and the southern uplands there stretches from sea to sea a tract of relatively low-lying ground known as the central valley of Scotland. Of diversified scenery, this tract, 50 miles broad and 120 miles long, trends from south-west to north-east, its northern margin stretching from Greenock to Stonehaven, and its southern side from near Girvan to Dunbar. This well-defined belt is occupied by the rocks of the Old Red Sandstone and Carboniferous systems. The Old Red Sandstone, in a strip 20 miles broad, abuts against crystalline schists along the northern margin, and as a much narrower belt fringes the Ordovician rocks of the southern uplands. The ground between is occupied by the Carboniferous formation over a tract of roughly 1,680 square miles, but once extending over an area estimated at 3,600 square miles. The coal-bearing Carboniferous rocks do not much exceed an area of 800 square miles, or about two-thirds the size of the Yorkshire-Nottinghamshire Coalfield.

The coalfields of Scotland are of Carboniferous Limestone age and of Coal-measure age, the two coal horizons being not infrequently referred to as Lower Coal-measures and Upper Coal-measures, but now generally termed the 'Limestone Coal Group' and the 'Coal-measure Group.' The Coal-measure Group occupies ten more or less well-defined basins. Most of these are infolds within Lower Carboniferous rocks, and typically illustrated by that of Midlothian. In one at least, that of Sanquhar, the Coal-measures fill up an old pre-Carboniferous hollow. As a whole, however, the inequalities of the pre-Carboniferous floor were filled in by Lower Carboniferous sediments, in which succession the Limestone Coal Group occupies a high position. The shape and outline of one of these hollows is preserved in the Douglas Coalfield.

The wide spread of the early Mesozoic formations of the

Carlisle basin, partly belonging to the Trias and partly to the Permian, has been preserved under volcanic rocks in the centre of the Ayrshire Coalfield, but elsewhere all signs

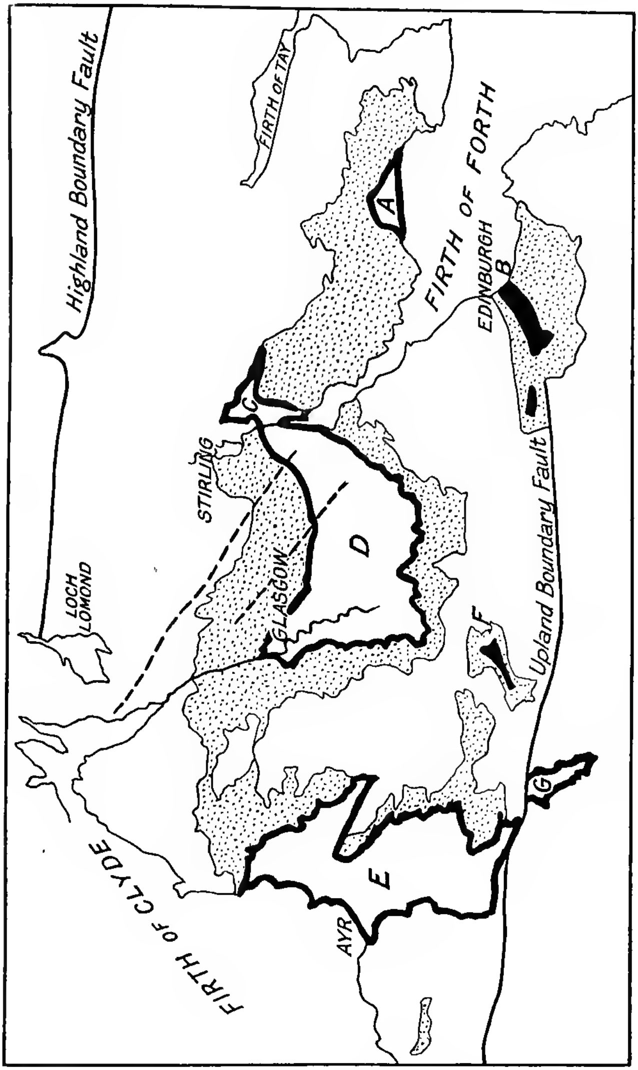


FIG 49.—SKETCH MAP OF THE COALFIELDS OF SCOTLAND.

A, Fifeshire Coalfield; B, Midlothian Coalfield; C, Clackmannan Coalfield; D, Central (Lanark) Coalfield; E, Ayrshire Coalfield; F, Douglas Coalfield; G, Sanquhar Coalfield. Stippling represents Lower Carboniferous Rocks. Scale, one inch = 20 miles.

of later formations have been swept away—if, indeed, they were ever deposited—though the red colour of parts of the Carboniferous strata has been attributed to staining derived

from a former extension of red rocks. The chief cover of the Carboniferous strata consists of Glacial clays, sands, and gravels, spread in broad sheets over most of the low-lying ground and concealing much of the coal-bearing rocks. Old and deep channels, draining into the former and much deeper trenches of the Clyde and Forth, have been completely infilled with these glacial deposits, and are not infrequently encountered underground in mining the coal-seams up to their basset edges along these buried channels.

The central valley is celebrated for the exhibition of volcanic phenomena of early Carboniferous and Permian ages, also for igneous intrusions extending from early Carboniferous to late Tertiary times.

Individual seams of coal are less continuous than in the English coalfields, and, coupled with areas spoiled by igneous rocks, makes coal-mining, as a whole, more uncertain than in England. Both the Limestone coals and those of the Coal-measures are highly bituminous. Steam coals of the Welsh or Yorkshire type are very limited in number and extension. Gas coals, on the other hand, are common, and the oil shales furnish the chief raw material of the oil industry of Britain.

The Carboniferous system, its divisions, and the formations connected with them have been grouped in the following descending order:

GENERAL TABLE.

(*a*) Sedimentary Formation.

Formation.	*Chief Localities.*	*English Equivalent.*
Glacial sands, gravels, and boulder clay.	General.	Glacial sands, gravels, and boulder clay chiefly in the northern counties.
Permian.	Ayrshire, Nithsdale, Annandale.	Penrith Sandstone and Marls.
Upper Coal-measures.	Absent.	Upper Coal-measures.
Middle (Westphalian) Coal-measures.	Only in part.	Middle Coal-measures.
Lower (Lanarkian) Coal-measures.	General.	Lower Coal-measures.
Millstone Grit.	General.	Millstone Grit.
Upper Limestone Group.	Fifeshire, Midlothian, Lanarkshire.	Carboniferous Limestone Series in the north; upper part of Carboniferous Limestone in the south.
Limestone Coal (Edge Coal) Group.	Fifeshire, Midlothian, Lanarkshire.	
Lower Limestone Group.	Fifeshire, Midlothian.	
Calciferous Sandstone Series.	Fifeshire, West Lothian.	

(*b*) Igneous Rocks.

Formation.	*Chief Localities.*	*English Equivalent.*
Tertiary, W.N.W. dykes.	Lanarkshire.	Cleveland Hills, North Staffordshire.
Permian, volcanic, and intrusive rocks.	Ayrshire and basin of the Firth of Forth.	Devonshire and Midland.
Carboniferous, volcanic, and intrusive rocks.	1. Plateau type: Ayrshire, Renfrewshire, East Lothian. 2. Puy type: Ayrshire, Renfrewshire, West Lothian, Fifeshire.	Great Whin Sill, Derbyshire toadstones.

Pronounced palæontological characters between the fossil plants and fossil fishes distinguish the Upper from the Lower Carboniferous rocks, though the boundary-line lies in a sandstone-shale series (Millstone Grit). Numerous bands of fossiliferous limestone, from 1 to 100 feet thick, occur in the Lower and not in the Upper Division. Coal-seams are common to both, but the most persistent beds, and those hitherto yielding the bulk of the output, are found in the Upper Division.

In the Calciferous Sandstone Series a few inferior coals occur in the upper part, but the series is economically important from its yielding the oil shales of the Lothians, and is geologically interesting in the great development of volcanic rocks illustrated by numerous necks and the wide-spreading and thick lavas of the Clyde plateau, the volcanic rocks of Arthur's Seat and of Burntisland. The combined thickness of the lava flows and volcanic material exceeds 1,500 feet. The thick and well-known Burdiehouse Limestone, near the middle of the oil shale group, is of fresh-water origin. Marine limestones occur near the top of the group notably the Holly Bush Limestone 200 feet below, and the Blackbyre Limestone 50 feet below the Hurlet Limestone. The fauna is characteristic of the upper subzone (D 2) of the *Dibunophyllum* zone. Below the Hurlet Limestone the Basket shell bed yields a typical Pendleside fauna. A characteristic flora includes species of *Sphenopteridium, Phacopteris, Adiantites,* and *Archæopteris.*

The Carboniferous Limestone Series has been subdivided into three groups in descending sequence:

3. Upper Limestone Group, from the bottom of the Index Limestone to the top of the Castlecary Limestone, 200 to 1,000 feet.

2. Coal (Edge Coals) and Ironstone Group, from the top of the Top Hosie Limestone to the Index Limestone, 700 to 1,000 feet.

1. Lower Limestone Group, from the bottom of the Hurlet Limestone Coal to the top of the Top Hosie Limestone, 300 to 1,000 feet.

Bands of limestone ranging from 2 to 80 feet in thickness form the basis of the classification. These and other bands are known under different names, but lately an attempt has been made to standardize them.

Standard Name.	*Local Name.*
Castlecary Limestone	No. 6 (Edinburgh), Levenseat, Craigenbuck.
Calmy Limestone	No. 5 (Edinburgh), Janet Peat (Fife), Arden, Robroyston, Shirva, Limekilnburn, Gair. Dyke—Neuk, Hirst, Gill (Lanarkshire), Bluetower (Ayrshire).
Index Limestone	No. 4 (Edinburgh), Cowglen, Seven Feet (Lanarkshire), Ell Coal or Bilston, Highfield (Ayrshire).
Hosie Limestone	No. 3 (Edinburgh), Bilston, Chapel Point.
Hurlet Limestone	No. 2 (Edinburgh) or Gilmerton. Hurlet (Fife), Eelwell (Northumberland).

Intermediate but impersistent limestones are known as 'extra' limestones.

From an economic standpoint, chief attention must be given to the middle subdivision, as containing several important coals and beds of Black Band Ironstone. It is in this group that the chief reserves of coal are situated, but some coals also occur in the lower and upper subdivisions.

Palæontologically, the upper group is distinguished from the lower by the differences in the characters of evolutionary members of the coral *Zaphrentis delanouei*, M. Ed. and H. In the underside of the Calmy Limestone, *Edmondia punctatella* is characteristic, and though *Productus latissimus* is abundant at various horizons in the Upper Limestone Group it is not known in the Castlecary Limestone. It is interesting to note the occurrence in the Edge Coal Group of *Anthracomya wardi* and *A. phillipsi*, which are regarded as zonal fossils of the Coal-measures of England (p. 46). In the flora *Lepidodendron veltheimianum*, *L. rhodeanam*, and *Sphenopteris elegans* are characteristic.

A Millstone Grit Series is recognized throughout the Scottish coalfields, and is peculiar in that the palæontological

break between the Upper and Lower Carboniferous rocks occurs in this sandstone-shale group at about 150 to 200 feet above the Castlecary Limestone of the Midlothian Coalfield, and at the horizon of a marine bed with *Lingula mytiloides* and *Productus semireticulatus*.

In the lower portion of the Millstone Grits of Midlothian, Lanarkshire, and Stirlingshire, a marine band contains a lamellibranch fauna, of which one-half of the species resembles that of the Coal-measures of Nebraska and Illinois.

As in England, the Coal-measures consist largely of shales, (termed ' blaes '), shaly sandstones, or sandy shales (termed ' fakes '), and fireclays. Economically the most important subdivision of the Carboniferous system in Scotland, in containing the seams from which the bulk of the coal has been and is obtained, the chief point of geological interest is centred in a marine band (Skipsey's) developed at or near the summit (Table, p. 274), the fossils of which forcibly recall those found in the Mansfield Marine Bed of Nottinghamshire and Yorkshire. As in England, *Carbonicola robusta* indicates a low horizon.

Ichthyological life zones cannot be established in the Upper Carboniferous rocks, since the same estuarine fish fauna is common to the lower and middle subdivisions of the Coal-measures. On the other hand, it is claimed for the plants that their vertical distribution in the Lower Coal-measures (Lanarkian) differs from that in the Middle Coal-measures (Westphalian), including in the latter all the measures above the Ell Coal of Lanarkshire and all the barren red measures of Midlothian, Fife, Lanark, and Ayrshire. Many of the species found in the Lanarkian are common to the Westphalian, but some plants are restricted to each subdivision. Thus *Lonchopteris eschweileriana* is characteristic of the Lanarkian; but the genus *Odontopteris* is confined to the Westphalian, as is also the very common plant *Pecopteris miltoni*.

Solid formations later than the Carboniferous rocks are confined to the red sandstones and shales of Ayrshire, Nithsdale, and Annandale of Permo-Carboniferous, Permian, and possibly of Triassic ages. Volcanic vents and sheets of diabase, picrite, olivine-basalt, andesite, and tuff are associated with them in Nithsdale and Ayrshire. Numerous vents between St. Andrews and Largo in Fifeshire have been also referred to the same volcanic period. This volcanic episode is a recrudescence of that so actively displayed in

Calciferous Sandstone times, and which died away before the final deposition of the Millstone Grits.

Few of the coals have a wide lateral extension, especially among the seams of the Carboniferous Limestone Series, thus rendering it difficult to correlate the coals in separated basins or even in the same basin. In the well-defined Midlothian basin the correlation of the seams on either side of this narrow basin remains uncertain except in the identification of the Great Seam ; and of the Parrot Seam on the south-east side and that of the North Coal on the west. Further, the seams are thickest and most numerous on the north-west side. In Fifeshire the Edge Coal Group is not so well developed as on the opposite side of the Forth at Joppa ; consequently, its undersea development is less promising from the Fifeshire border than from the Midlothian sea margin. In the Midlothian basin the seams of the Coal-measures show a tendency to decrease in thickness in a southern and eastern direction. In Fife, coal-seams of Coal-measure age are better developed than on the Midlothian side of the Forth. Probably the Splint Coal, towards the middle of the Lower Coal-measures of the Central (Lanark) Coalfield, is the most persistent of the seams of coal.

In composition the majority of Scotch coals, both in the lower and upper divisions of the Carboniferous formation, belong to the bituminous class. There are several second-class steam coals; some in the vicinity of igneous intrusions become anthracitic, but they then possess a higher ash percentage than the parent coal. This conversion does not apply to the Lower Drumgray Coal, one of an anthracitic type, of which the composition appears to be original. In gas and coking coals the Scotch coalfields are highly favoured. Many of the seams are in the form of cannel or 'parrot,' and are particularly well developed in the Edge Coal Group, either as distinct seams or forming one of the components of a compound seam. The Lesmahagow Gas Coal (p. 273) of the Auchenheath district has long been known as a gas coal of exceptional quality, and has been used as a standard gas coal with a yield of 11,888 cubic feet of gas per ton as compared with 10,616 cubic feet for a first-class Durham coking coal, and 10,512 cubic feet for the Silkstone Coal of Yorkshire. Still more widely known is the now exhausted Torbanehill Gas Coal of the Armadale district, rich in kerogen and a good oil-producer.

FIFESHIRE COALFIELD.

The Fifeshire Coalfield, extending roughly parallel with the Firth of Forth for nearly 32 miles, has an average breadth of about 5½ miles, and includes an area of roughly 170 square miles, of which a triangular-shaped part of 20 square miles between Dysart and Leven is occupied by productive Middle Coal-measures, containing the well-known Dysart Main Coal, which reaches a thickness of 23 feet. Reserves, including part of Kinross, are estimated at 3,742,336,644 tons.

The general Carboniferous succession is the same as in the Central Coalfield, but the Limestone Coal Group is richer in coal, and the Upper Limestone Group also contains some workable seams. There is also an interesting development of red Middle Coal-measures which succeed the productive Middle Coal-measures, and are excellently displayed along the coast.

In Central and Western Fifeshire the Lower Carboniferous rocks are involved in a main basin fold that is split up by faulting and plication into minor basins, of which those of Dunfermline, Lassodie, and Kelty, Lochgelly, Kirkcaldy are the most important. Situated on the western borders of the county are the coalfields of the Saline, Oakley, and Torryburn, geologically connecting the Fifeshire Coalfield with that of Clackmannan, which in turn is a northern prolongation beneath the Forth of the Central Coalfield of Scotland. In Eastern Fifeshire the Carboniferous Limestone Series stretches between Markinch to Pittenweem, and northwards to near Cupar and St. Andrews, covering an area of about 40 square miles known as the East Fifeshire Coalfield. It is of interest in furnishing two seams of coal of workable thickness in the Calciferous Sandstone Series, and known under the names of Back Coal (7 feet) and Fore Coal (3 feet 4 inches). Numerous faults and igneous intrusions, developed on a greater scale than elsewhere in Scotland, traverse the coal-bearing strata.

Between the Hosie Limestone and Index Limestone the chief coals of Dunfermline are the Dunfermline Splint Coal, 130 feet above the Hosie Limestone, followed in upward succession by the Five Feet, Eight Feet, Swallowdrum, Cairneubbie, and Six Feet. The coals of the Kelty coal-basin above the Dunfermline Splint are named in ascending order: Gin, Lochy, Bank (Lochgelly Splint), Splint (Kinglassie Splint), Jersey, and Main. In the Saline Valley the coals

correspond with those of Dunfermline. In addition, there are some higher workable seams—Six Feet Coal and Four Feet Coal.

The Upper Limestone Group of the Capeldrae Coalfield contains the following seams, each of which is worked: Lochore Parrot, Capeldrae Parrot, Craig coals. The Craig and Capeldrae Parrot, each 4 feet thick, are separated by 500 feet of strata, of which more than one-half consists of 'whinstone.'

The Millstone Grits have a limited outcrop, except along the west side on the Clackmannan border.

The productive Middle Coal-measures, 1,600 feet thick, contain the following seams of over 2 feet in thickness, commencing with the lowest coal, about 200 feet above the top of the Millstone Grit: Seven Feet, Dysart Main, Mangie, Brankstone, Bowhouse, Wood, Parrot, Bush, Chemiss, Lower and Upper Coxtool, Barncraig, Wall, the last mentioned being succeeded by nearly 300 feet of barren grey measures before passing up into the Red Barren Group of the Middle Coal-measures. Skipsey's marine bed lies 210 feet above the Barncraig Coal and 110 feet above the Wall Coal. Near Dysart, the Main Coal gives a section of: Roof coal, 4 feet; stone, 1 inch; spar coal, 1 foot 8 inches; stone, 1 inch; head coal, 1 foot 8 inches; clean coal, 1 foot 9 inches; stone, 4 inches; splint, 10 inches; stone, 2 inches; nether coal, 3 feet 6 inches; stone, 1 inch; ground coal, 3 feet 7 inches; stone, 9 inches; thief coal, 5 feet—giving a thickness of 23 feet 7 inches, which is reduced to 10 feet in a distance of three miles to the north and east. From its thickness (9 feet) the Chemiss Coal is known locally as the Main Coal. It consists of crow coal, 1 foot; dirt, 1½ inches; house coal, 4 feet; dirt, 1 inch; Binks Steam Coal, 2 feet 1 inch; dirt, 1 foot; coal, 2 feet 6 inches.

The grey productive measures graduate upwards into a Red Barren Group consisting of red, purple, grey, and white variegated sandstones, and red shales, clays, and marls, with entomostracan limestones and a few coals of inferior quality, having a combined thickness of not less than 1,000 feet, without reaching the summit of the group. Towards the top of the sequence, shales associated with two thin coals, have yielded many plants of a Middle Coal-measure facies, several genera of fishes, and *Anthracomya wardi*. But the group as a whole is poor in fossils, and, lacking the fossil evidence, the beds would have been unhesitatingly correlated

with the Upper Coal-measures of Central England. These red measures and the beds below are excellently displayed in a nearly continuous coast section on the beach and along a range of low cliffs between Dysart and Leven for a distance of seven miles. Skipsey's Marine Bed has been noted in a ravine at East Wemyss and along the foreshore east of Wemyss Castle.

The main syncline, as previously mentioned, is complicated by faulting with a prevalent west-north-west trend in the lower coal-bearing group. In the Dysart coal-basin the trend of the faults is in an east and west direction, with a predominant downthrow to the south, resulting in a multiplication of the outcrops. A powerful boundary fault trends eastwards past Cleish to the northern end of the Kelty Coalfield. At Cleish it has a displacement of more than 2,000 feet, which has increased to 3,000 feet on the flanks of Benarty Hill, at which place the higher coals are brought down against the Old Red Sandstone. With an increasing throw it forms the northern boundary of the Kinglassie Coalfield, but diminishes eastward to 500 feet north of Leven, where it runs out to sea.

Volcanic eruptions, represented by lavas and tuffs, were particularly active during the deposition of the Upper Calciferous Sandstone Group. Volcanic phenomena are excellently illustrated in the Saline Hills. Intrusive igneous rocks in the form of sills and bosses abound, but there are only a few dykes in the Carboniferous regions. Volcanic necks, notably at Lundin Links, pierce the Red Barren Measures, and not improbably belong to the Permian volcanic episode of Ayrshire.

The coals are chiefly of the bituminous class. The Dunfermline Splint Coal, celebrated in Scotland as a steam coal, gives an analysis of: Carbon, 81·20; hydrogen, 5·16; sulphur, 0·84; nitrogen, 1·33; oxygen, 10·61; ash, 0·86. By the action of igneous intrusions the Splint and Gin coals of the Kelty Coalfield have been converted into a bastard anthracite. An analysis of the Splint Coal shows: Volatile matter, 24·27; fixed carbon, 73·56; ash, 1·42; sulphur, 0·27. Cadell's Parrot Coal of Western Fife, or Lochore Parrot of Lochgelly, is a well-known cannel of the Upper Limestone Group. The Capeldrae Parrot Coal of the Capeldrae-Lochore basin, consisting of two bands, 1 foot 8 inches and 1 foot 8 inches respectively, is stated to yield 70 to 81 gallons of oil per ton.

Clackmannan Coalfield.

Continuing their westerly inclination, the Lower Carboniferous strata on the Fifeshire border bring in an area six miles long and four miles broad of Lower Coal-measures around Alloa and Clackmannan. The Ochill Hills form the northern boundary; and, rising west of Alloa, the Millstone Grits come to the surface and form the western margin. The Forth constitutes the southern boundary, but both Coal-measures and the Lower Carboniferous rocks are connected under the Forth with the basin fold enclosing the northern prolongation of the Central (Lanarkshire) Coalfield of Scotland. There is a southern extension of the coals into detached portions of Perthshire and Kincardine, and two small detached areas at Dollar and Blairingone. The available resources are estimated at 443,800,366 tons.

Coal-seams in the Carboniferous Limestone are thinner than in Fifeshire. Above the Millstone Grits the Lower Coal-measures are well developed, yielding the following descending series of coals and measures: Measures, 100 feet; three rough coals in measures, 200 feet; Upper Five Feet (8 feet) and Four Feet coals; measures, 40 feet; Nine Feet Coal (consisting of parrot, 8 inches; rough and splint coal, 9 feet); measures, 120 feet; Mosie Coal, 1 to 3 feet; measures, 40 feet; Lower Five Feet or Cherry Coal, 5 feet; measures, 12 feet; Splint Coal, 3 feet; measures, 33 feet; Coalsnaughton Main Coal, 5 feet 10 inches, with a parting of blaes. The Alloa Nine Feet is correlated locally with the Splint Coal of Lanarkshire, and the Lower Five Feet with the Kiltongue Coal. Over much of the area the higher seams are exhausted, and the chief workings are in the Nine Feet, Lower Five Feet, and Splint coals.

Along the northern boundary of the coalfield the Coal-measures end off abruptly at a fault against the older rocks of the Ochill Hills. A buried valley filled with Drift, cutting off all the upper seams, runs along the foot of the hills, forming part of the ancient drainage system of the Forth. Drift also obscures much of the outcrop on the west. The coals are classed as house, manufacturing, and steam. The Lower Five Feet Coal, known commercially as the Alloa Jewel Coal, gives an analysis of: Fixed carbon, 55·61; volatile matter, 36·93; sulphur, 0·58; ash, 1·16; moisture, 5·72.

Central (Lanarkshire) Coalfield.

Alluvial deposits covering glacial gravels and clays border the north banks of the Forth between Alloa and Clackmannan. On the south side of the river these superficial deposits cover a wide area between South Alloa and Grangemouth. It is known, chiefly through mining operations, that the Coal-measures lie beneath these superficial deposits around and to the south of Airth, and thus connect, though with some interruption by east and west faulting and folding, the coalfield north of the Forth with the northern extension of the Lanarkshire coal-basin. This constitutes more than 50 per cent. of the area known as the Central Coalfield, the largest and most important coal-mining district of Scotland. Including the coal-bearing Lower Carboniferous rocks, the area of about 1,700 square miles is continuous with the coal-mining districts of parts of Renfrewshire, Dumbartonshire, Stirlingshire, Linlithgowshire, and Edinburghshire. Dumbarton, Paisley, and Glasgow are situated in the west part of the area; Coatbridge and Airdrie towards the centre; Linlithgow and Bathgate in the east; Carluke and Hamilton in the south. More than 60 per cent. of the output of Scottish coalfields has been obtained from the Lanarkshire basin, the annual output amounting to over 17,000,000 tons, or twice that obtained from Fifeshire, the next largest coal-producing county. Reserves are estimated at 2,604,515,996 tons.

The Carboniferous succession is as follows:

Upper Carboniferous	Barren red and grey measures (Middle or Westphalian Coal-measures down to the Ell Coal). Productive Coal-measures (Lower or Lanarkian Coal-measures). Millstone Grit.
Lower Carboniferous	Upper Limestone Group. Coal and Ironstone Group. Lower Limestone Group. Calciferous Sandstone.

A few thin coals and ironstones occur in the Calciferous Sandstone Series and in the Lower Limestone Group, but as in other Scotch coalfields the important coals of the Lower Carboniferous rocks are found in the Coal and Ironstone Group that contains the bulk of the reserve coal. The group includes the strata occurring between the top of the Top Hosie Limestone at the base and the bottom

of the Index Limestone at the summit. Owing to variability in their development the correlation of the seams is difficult. The following table shows the general order of their occurrence and approximate relative positions in the west and east:

Glasgow Area.	*Denny and Plean.*	*Bathgate and Bo'ness.*
Index Limestone.	Index Limestone.	Index Limestone.
Measures.		
Twechar Coal.	Measures with Upper and Lower Denny.	Measures with Balbardie Gas Coal.
Measures.		
Upper Possil Coal (Meiklehill Main).	Black Band Ironstone.	China, Two Foot, Fiddle, and Jewel coals.
Upper Possil Ironstone.		
Measures.		
Batchie Ironstone.		
Measures.		
Main Ironstone.		
Measures.		
Fourteen Inch Ironstone.		
Measures.		
Main Possil Coal.	Bannockburn Main Coal.	Main Coal.
Measures.		
Lower Possil Coal.		
Measures.		
Shale Coal.	Measures with some coals and ironstones.	Measures with some coals and ironstones.
Measures.		
Jubilee Coal (Jordan Hill, Black Band Ironstone).		
Measures.		
Gas Coal.		
Measures (with Black Metals).		
Lower Garscadden Ironstone.		
Measures.		
Garibaldi Ironstone.		
Measures.		
Kilsyth Coking Coal.	Kilsyth Coking Coal.	Wilsontown Gas Coal.
Measures.		
Top Hosie Limestone.	Top Hosie Limestone.	Top Hosie Limestone.

The group is best known from the occurrence of the Possil ironstones and coals situated about 250 feet below the Index Limestone and 450 feet above the Top Hosie Limestone. The chief ironstones are of the Black Band

variety, and are three in number—Upper Possil, Main, and Lower Possil. They are always more or less laminated or intercalated with thin seams of coal, the ironstone bands averaging about 6 inches in thickness, with a tendency to be replaced entirely by coal. The Kilsyth Coking Coal, 400 feet above the Top Hosie Limestone of the Glasgow area, is of uniform high quality, producing excellent coke. A proximate analysis gives: Fixed carbon, 67·82; volatile matter, 28·45; ash, 2·01; moisture, 1·72. Above this seam a coal varying in position and thickness occurs locally in the position of the Lesmahagow Gas Coal. Higher coals in the sequence are the Soft (Cloven), Wee, Haugrigg or Main, and Twechar. In the Denny and Plean district the Bannockburn Main Coal is important, as is the Main Coal of the Bathgate area. In the Bannockburn Coalfield, Stirlingshire, the following descending sequence occurs below the Index Limestone: Measures with several thin coals, 180 feet; Black Band Ironstone; measures, 35 feet; Greenyard Coal, 2 feet 4 inches; measures, 60 feet; Auchenbowie Coal; measures, 120 feet; Bannockburn Main Coal, 3 feet 6 inches; measures with two coals, 420 feet; limestone. The Bannockburn Main Coal, commercially known as the 'Bannockburn Wallsend Drawing-Room Coal,' furnishes an excellent house coal with the following analysis: Fixed carbon, 66·50; volatile matter, 29·10; ash, 2·10; sulphur, 0·05; water, 2·25.

In the southern part of the area the best-known area is that of Carluke and Auchenheath, containing the famous Lesmahagow Gas Coal, which is often referred to as a standard gas coal, yielding 11,830 cubic feet of gas, with an illuminating power of 35·25 candles. The Lesmahagow Gas Coal lies towards the bottom of the Limestone Coal Group, somewhat near the horizon of the Kilsyth Coking Coal. It is thin and unworkable near Carluke, but thickens to the south in the direction of Auchenheath, where it is sometimes 2 feet thick.

In Renfrewshire coals in the position of the Possil Group are in descending sequence: Sclutty Coal, 3 feet; Smithy Coal, 1 foot 6 inches; Rough Coal, 2 feet; Stinking Coal, 1 foot 9 inches; Geordie Coal, 2 feet 2 inches; Two Feet Coal, 2 feet 2 inches; Stone Coal, 2 feet. In the Lower Limestone Group the Hurlet Coal beneath the limestone of this name reaches a thickness of nearly 6 feet of pyritous coal, overlain by alum shale. At Quarrelton, near Johnstone, the

seams of coal have been thrust over each other, giving rise to a compound seam consisting of: Coal, 17 feet; clay, 1 foot; coal, 9 feet; clay, 2 feet 3 inches; coal, 10 feet; clay, 1 foot; coal, 27 feet; clay, 1 foot; coal, 9 feet; clay, 2 feet 3 inches; coal, 10 feet; clay, 1 foot; coal, 10 feet; with a fireclay and sandstone roof.

In the Upper Limestone Group the Castlecary Limestone is not so persistent as the other bands. The Calmy Limestone, a hard, blue, fine-grained, compact stone, is very persistent, and characterized by the fossil shell *Edmondia punctatella*. A coal—Hirst Coal—occurs below it.

In the Glasgow area the thickness of the Millstone Grit does not much exceed 300 feet, but it increases in a north-east direction to 640 feet near Slamannan, and to 960 feet in the Plean area. A few thin coals are found, but the economic value of the fireclays is of considerable importance, as they yield the well-known Glenboig fireclay of Glenboig, Garnkirk, and Castlecary. Interest is attached to some shelly calcareous shales (about 30 feet above the Castlecary Limestone), containing the characteristic orthotetid shell *Derbya*. The band is known as the 'Cement Stone.' With it is associated the fauna, having a close affinity with the lamellibranch fauna of the Coal-measures of Nebraska, but now known to occur also in the Index Limestone, Lower Limestone of Fifeshire, and the Calciferous Sandstone of Kirkcudbrightshire. Among the fossil shells that of *Prothyris* is interesting, as this fossil occurs in the Mansfield Marine Bed at Maltby Colliery, Yorkshire, at an horizon high up in the Middle Coal-measures.

The succeeding productive Coal-measures cover a wider, though largely drift-covered, area than elsewhere in Scotland. Numerous seams have long been worked, and have furnished the main supply of the Clyde Valley. They occur in the following descending order, with the thicknesses of the intervening measures and coals given in feet:

LANARKSHIRE.

Middle (Westphalian) Coal-measures	Measures. Skipsey's Marine Bed. Measures, 27. Palacecraig Black Band Ironstone. Measures, 45. Upper Coal, 2. Measures, 60. Ell Coal, 4.

	Lanarkshire.	Stirlingshire.
Lower (Lanarkian) Coal-measures	Measures, 40.	
	Pyotshaw Coal, 3 ft. 6 ins.	
	Measures, 20.	
	Main Coal, 4 ft. 6 ins.	
	Measures, 45.	
	Humph Coal, 3.	
	Measures, 30.	
	Splint Coal, 4 ft. 6 ins.	
	Measures, 12.	
	Virgin Coal, 2.	
	Measures, 70.	
	Airdrie B.B. Ironstone and Coal, 2 ft. 3 ins.	
	Measures, 60.	
	Virtuewell Coal, 3.	Lady Ha, Virtuewell, Wee.
	Measures, 30.	
	Ladygrange Coal, 3.	Virtuewell, Five-Quarter, Diamond, Ladygrange, Miller, Two Feet, Mussel Band.
	Measures, 40.	
	Kiltongue Mussel Band Coal, 2.	
	Measures, 36.	
	Kiltongue Coal, 6.	Kiltongue, Main, Craw or Crow.
	Measures, 36.	
	Upper Drumgray (Shott's Furnace), 3.	Upper Drumgray, Splint, Carron Main.
	Measures, 40.	
	Lower Drumgray, 2.	Lower Drumgray, Coxrod.
	Measures, 80.	
	Balmoral (Clefted, Mill), 1 ft. 6 ins.	
	Measures (120 ft.), with Slaty Band Ironstone near the base.	

No constant base is recognized, but it is taken at the horizon of the Crofthead Slaty Band Ironstone when this bed is present. In places, a marine bed with *Lingula*, goniatites, etc., makes its appearance under shales containing *Carbonicola robusta* at about this horizon. The Kiltongue Coal is recognized by a mussel-band ironstone occurring 30 to 60 feet above the seam. The Splint Coal, slightly above the middle of the Lower Coal-measures, is the most constant of the Lanarkshire seams. It is not to be confused with the Splint, Carron Main, or Hard Coal of Falkirk, which is on the horizon of the Upper Drumgray Coal. In the eastern part of the coalfield, and

particularly around Torbane Hill in Linlithgowshire, the well-known boghead coal occurs near the base of the Lower Coal-measures on about the horizon of the Slaty Band Ironstone. At Armadale its position is beneath the following sequence: Upper Cannel Coal, 2 to 4 feet; strata, 36 feet; Mill Coal, 1 foot 10 inches; strata, 54 feet; Ball Coal and ironstone, 2 feet 6 inches; strata, 20 feet; Main Coal, 3 feet 10 inches; strata, 60 feet; Colinburn Coal, 2 feet 9 inches; strata, 10 feet; Torbane Hill Gas Coal and ironstone. The Upper Cannel seems to correspond to the Shott's Gas or Clefted Coal. The Torbane Hill Coal is practically exhausted. Like most cannels and canneloid substances, the band was lenticular, ranging in thickness from 0 to nearly 2 feet. Its composition is: Carbon, 63·936; hydrogen, 8·858; nitrogen, 0·962; oxygen, 4·702; sulphur, 0·320; ash, 21·22. Besides furnishing a rich gas coal, it yielded also 128 gallons of oil per ton. In parts of the Rosehall field several seams are spoilt by the presence of numerous thin veins of carbonate of lime, iron, and magnesia. These are called 'burnt' coals, but there is no reason to suppose these calcareous coals have been subjected to special heat, or is there any clear evidence why certain areas should be affected in this way. Analysis of the clean and of the coalyparts of the calcareous coal shows that both are of a bituminous character, and not anthracitized, such as the Upper Drumgray Coal at Kippsbyre, in which the clean coal gives an analysis of fixed carbonaceous matter, 48·91; volatile matter, 26·52; ash, 5·33; moisture, 9·24; and the burnt Upper Drumgray an analysis showing fixed carbonaceous matter, 48·92; volatile matter, 23·32; ash, 25·78; moisture, 1·98.

Skipsey's Marine Bed has been found at Drumpark, west of Coatbridge, and along the North Calder River near Palacecraig, east of Coatbridge. At the latter locality the band consists of 6 inches of impure dark grey limestone resting on 2 inches of dark grey shales. It lies 318 feet above the Upper Coal, which is about 300 feet above the Splint Coal of the Clyde basin. The fossils include *Lingula squamiformis, Productus, Posidoniella sulcata, Pterinopecten papyraceus, P. carbonarius, Posidonomya becheri,* Goniatites.

The Barren Red Middle Coal-measures (usually termed Upper Red Barren Measures, though they are not the equivalent of the Upper Coal-measures of England) cover considerable areas in the Clyde Valley south-east of Glasgow. They consist of reddish sandstones and shales in thick beds

with thin, compact, unfossiliferous, cream-coloured limestones and a few thin coals. Their summit is not seen, but their thickness exceeds 1,000 feet. Whether they rest conformably or unconformably on the grey measures has not been clearly demonstrated.

With the exception of the marine fauna of Skipsey's Marine Band and of that above the Slaty Band Ironstone, the invertebrate fauna is not of much variety. A band with *Pterinopecten papyraceus* and *Orthoceras* has been recorded from one locality in a bed above the Kiltongue Coal. A 'mussel band' below the Virgin Coal yields in abundance *Anthracomya adamsi. A. modiolaris, Carbonicola robusta, C. aquilina. Carbonicola robusta* is particularly abundant in the roof of the Upper Drumgray Coal, but is very rare or absent in the roof of the Lower Drumgray Coal. Comparatively few fossil plants have been obtained from the Westphalian (Middle) Coal-measures.

The Central Coalfield occupies a triangular-shaped area, with its apex at Govan and its base stretching from Stonehouse, west of Lanark, to near Grangemouth, due to the intersecting of an east and west system of faulting with another set running from south-east to north-west. A large proportion of the faults are strike faults. In combination with a general low inclination of the strata this results in much duplication of outcrops. A large fault, introducing the Red Barren Measures, skirts the coalfield on the south-west. Along the northern boundary the Comedie Fault and others having the same general easterly trend bound the north-west part of the basin. On the east side, between Carluke and Grangemouth, the Lower Coal-measures succeed naturally the Millstone Grit formation. East and west faulting subdivides the northerly extension of the main basin into several isolated sub-basins. Those of Airth and of Carron are examples, while the Banknock Coalfield consists of an outlying strip of Coal-measures let down by two east and west faults in a deep trough between Carboniferous Limestone on the north and Millstone Grit on the south. The Hamilton coal-basin is exceptionally free from small faults. Igneous intrusions are common, except between Govan and Hamilton.

Outcrops of quartz dolerites extend eastwards from Airdrie to Caldercruix and beyond. Some of the sills have been proved for a thickness of over 140 feet. When met with underground they are known as 'floats,' and are not infre-

quent about the horizon of the Drumgray coals. East and west quartz dolerite dykes are exemplified, among others, by the Lenzie-Torphichen dyke that extends between these two places over a distance of twenty miles, and having an average width of 40 to 50 yards. They are nearly vertical. As a rule the coal is not destroyed for a greater distance from the intrusion than half the width of the dyke, while thin quartz dolerite sills often destroy large areas. Dykes, generally much decomposed, trending west-north-west also occur. Contemporaneous volcanic activity together with igneous intrusions are extensively developed in the districts of Bathgate, Linlithgow, and Bo'ness in the Lower Carboniferous formation, though a short distance to the east and south-east in the Midlothian coal-basin there is no trace of contemporaneous igneous activity in this division of the Carboniferous system. The volcanic rocks attain their greatest development two or three miles south of Linlithgow. In the Bo'ness district most of the contemporaneous igneous rocks are in the form of basaltic and much decomposed doleritic lavas mixed with subordinate bands of volcanic ash.

The most extensively worked seams of the Lanarkshire Coalfield are Drumgray, Kiltongue, Virtuewell, Virgin, Splint, Humph, Main, Pyotshaw, Ell. These seams furnish gas, house, steam, and manufacturing coals. Bituminous coals predominate. In the Stirlingshire part of the basin the seams chiefly worked are the Drumgrays (Coxrod), Main, Diamond, Splint, and the Ball, Mill, or Third Drumgray below the Coxrod. An analysis of the Kiltongue Coal of Larkhill gives: Fixed carbon, 56·98; volatile matter, 28·73; sulphur, 0·33; ash, 1·04. Analyses of some seams are: Virgin Coal—fixed carbon, 56·40; volatile matter, 32·55; ash, 2·95; moisture, 1·98. Splint Coal—fixed carbon, 54·31; volatile matter, 36·22; ash, 2·20; moisture, 7·27. Main Coal—fixed carbon, 53·79; volatile matter, 35·84; ash, 1·28; moisture, 9·09. Ell Coal—fixed carbon, 55·70; volatile matter, 33·33; ash, 0·98; moisture, 9·99.

Cover.—Broad areas in the coalfield are covered deeply under glacial gravels, sands, and boulder clay frequently exceeding 100 feet in thickness. In many places these fill up wide hollows, and in others, as at the Monkland Collieries, occupy and level up old river channels. The obliterated channel of the Carron River is the best-known and most conspicuous example. Here, at Carronbank, the rock head lies 285 feet from the surface, and at three-quarters

of a mile farther down the river, bed rock is reached between 252 and 273 feet in two adjacent bore-holes. On Carronshore the ancient channel is 1,012 yards in width. In the workings of the Carron Company the Coxrod, Main, and Craw coals have their basset edges against these glacial accumulations. Off Bo'ness, again, a great thickness of boulder clay with stones comes on rapidly, and at Bridgeness has been proved to a depth of 570 feet.

Douglas Coalfield.

An area of about twenty square miles of Carboniferous strata surrounded by older rocks forms a self-contained basin detached from the Clyde Basin Coalfield by a belt of Old Red Sandstone, and separated by a col of the same rocks from the Carboniferous areas of Glenbuck and Muirkirk. It is sometimes named after the mining village of Lesmahagow, which, however, is situated on an outcrop of Old Red Sandstone. The coalfield is bounded and crossed by faults, but with the exhaustion of the best seams of the Clyde basin it is assuming some importance.

A complete Carboniferous sequence is present, but there is a successive overlap of its members with the development of conglomerates at several stages. In passing from south-west to north-east the rocks and the accompanying coals change rapidly. Below the Index Limestone the seams in descending order at Bankend and Auchlochan are: Smithy (Ell), Three Feet (Dross), Four Feet (locally Ell), Nine Feet or Splint, Six Feet, and Macdonald coals. The Six Feet and Nine Feet are the chief seams, and are sold for locomotive and gas-making purposes. At Ponfeigh, on the east, the seams are: Wee Drum, Big Drum, Skaterough, Kirkroad, Stony, Back, Rob, Fallowhill, Wood, from 2 to 5 feet in thickness. Above the Index Limestone a seam (gas coal) gives: Coal, 1 foot 6 inches; stone, 6 inches; cannel, 1 foot 8 inches; coal, 2 feet 5 inches; The rise is to the east at 45 degrees, in which direction the measures expand and at the same time contain more coal. The Big Drum at outcrop gives a section of cannel, 2 feet 6 inches; coal, 7 feet; and on the deep a section showing cannel, 4 inches; coal, 4 feet 6 inches.

The Middle Coal-measures of the Douglas Coalfield occupy a trough with an area of five square miles, including, near Glespin about 500 feet of red strata overlain by Red Barren Measures that overlap on to the Old Red Sandstone. The

seams in ascending sequence are: Kennox (4 feet 6 inches), Carmacoup, Nine Feet, Four Feet, Three Feet, Seven Feet. Of these coals, the Nine Feet and Four Feet may correspond to the Drumgray coals, the Three Feet to the Kiltongue, and the Seven Feet to the Virtuewell. The Seven Feet (7 feet thick) and Nine Feet (9 feet thick), both of good quality, are the chief seams.

Glenbuck and Muirkirk.

This small area of Lower Carboniferous strata is a prolongation eastward of the Ayrshire basin. It is about one mile across at Glenbuck, widening to about two southwestward. The general form is a trough with the Millstone Grit formation in the centre at Muirkirk, and Middle Coal-measures occupying the central part near Wellwood, southwest of Muirkirk. The coals are much interrupted by intrusions in the form of sills ('floats'), dykes, and necks. In ascending order the chief coals in about 250 feet of measures are Macdonald, Six Feet, Seven Feet, Ell, below the Index Limestone. The Index Limestone and Millstone Grit are separated by about 500 feet of strata containing some thin coals. South-west of Wellwood, Lower Carboniferous coals have been worked at Gasswater and Guelt. At the latter place coals, named after their thickness Twelve Feet, Eleven Feet, and Nine Feet respectively, are stated to have been of good quality. The Muirkirk seams are not generally of high quality, but are suitable for smelting purposes.

Ayrshire.

The Ayrshire Coalfield, in point of output, stands next to that of Lanarkshire. Coal-bearing Carboniferous strata extend from the borders of Renfrewshire in the north, past Kilwinning, to Dalmellington in the south, a distance of upwards of 25 miles, and stretch inland from the coast at Ayr to Sorn, a distance of 14 miles. Of this large area, no less than 60 square miles, containing most of the valuable seams, have been spoilt by igneous rocks. Excluding this 'burnt' region, the resources are estimated at 1,082,547,283 tons.

A broad expanse of Old Red Sandstone and igneous rocks separates the main Ayrshire coalfields from that of Lanarkshire. In the northern part of the county the Limestone

Coal Group is well developed, with several, though thin and inferior coals. It disappears under the Coal-measures near Kilwinning, and when it rises to the surface again near New Cumnock it does so in an attenuated form. The Millstone Grit formation, about 800 feet thick, consists of sandstones, grits, valuable fireclays, and thin coals. One of the fireclays, corresponding to the Lower Fireclay of Glenboig, is mined at Monkcastle, Dalry, for use in the steel, iron, and zinc furnaces, as well as for special purposes.

A complete development of the Lower Coal-measures is present in Ayrshire, comparable in general outline, but not in detail, with the succession in Lanarkshire. As shown in the subjoined table, they contain several coals known under different names:

Ayr.	*Cumnock and Lugar.*	*Kilwinning.*
Ell.	Ell.	M'Naught.
Crawfordstone.	Main.	Tourhall.
Three Dirt.	Claud.	Stone.
Diamond.		
Jewel.		
Ayr Hard or Splint.	Maid.	Main.
Coal.		Lady Ha.
Coal.		Kilwinning Ell.
Coal.		Kilwinning Main.
Black Band Ironstone Measures.	Lugar Black Band.	

In the Dalmellington area the seams above the Burnfoot Black Band (Ayr Black Band Ironstone) are: Lower Coking, Pennyvenie Splint, Upper Coking, Camlarg, Sloanstone, Minnevey, Chalmerstone, Diamond, Sillyhole, and several unnamed seams above, the thickness of measures totalling 1,400 feet as compared with 800 feet in the Ayr basin. The Black Band Ironstone measures correspond with the Lanarkshire Slaty Band Ironstone; and the Sillyhole Coal lies on or about the same horizon as the Ell Coal of Lanarkshire. At New Cumnock seams above the Black Band Ironstone are: Four Feet, Three Feet, Eight Feet, Lower Gas Coal (gas coal, 4 feet; common coal, 2 feet), Upper Gas Coal (gas coal, 1 foot; common coal, 5 feet), succeeded by 450 feet of measures with eight thin seams. The Kilmarnock Coalfield, everywhere bounded by faults, contains several seams upwards of 4 feet in thickness named Main, Stone, Major, Tourhall, and M'Naught coals. The Main Coal, 11 feet thick, including a parting, splits up westwards into the Splint, Turf, and Wee coals; eastwards at Galston

it is an undivided seam 7 feet thick. Skipsey's Marine Bed, 700 feet above the Sillyhole Coal, has been noted at Burnockhill, two miles south of Ochiltree, and in a glen near Craigmark. At the latter locality the middle of the band consists of black shales with a grey limestone containing dwarfed forms of *Chonetes buchiana*, *C. hardrensis*, *Productus semireticulatus*, *Posidoniella*.

Red Barren Measures resting, possibly with a slight unconformity, on the productive grey Coal-measures attain a thickness of 500 feet near New Cumnock. In the Ayr basin they consist of red and purplish-grey sandstones, red, purple, or lilac clays and shales, with inconstant thin bands of white limestone containing *Spirorbis*. Excellent sections are afforded by the Ayr between Sorn and Ballochmyle. Though closely resembling the red Middle Coal-measures of Lanarkshire, the presence of Spirorbis limestones suggests their inclusion in the Upper Coal-measures of Staffordshire. Between these red measures and the next sediments seen in the centre of the Ayr basin there intervenes a succession of lavas, with occasional partings of tuff, which dip gently into the basin under brick-red sandstones placed in the Permian formation chiefly on their lithological resemblance to the Penrith Sandstone of the Carlisle basin and Dumfriesshire.

Igneous intrusions abound in Ayrshire, rendering large areas of coal unprofitable. They are especially abundant about Dalmellington in the form of sills of dolerite lying more or less parallel with the lines of bedding. Outside the volcanic pear-shaped area of the Ayr basin the Coal measures are pierced by numerous pipes, filled in with agglomerates composed chiefly of different volcanic rocks which closely resemble the Permian lavas. Necks of this character are numerous in the Dalmellington Coalfield.

The coals of Ayrshire are chiefly of the bituminous type. At Caprington a seam next below the Major Coal has been converted by a whin intrusion into a bastard anthracite having a composition of: Fixed carbon, 83·9; volatile matter, 11·1; ash, 3·2; water, 1·8. Cannels for gas-making have been extensively mined, and in a less degree for oil. An analysis of the New Cumnock Cannel Coal gives: Coke, 58·33; volatile matter, 36·67; water at 212°, 5·00. The coke analysis is: Carbon, 88·58; sulphur, 0·62; ash, 10·80. Around Kilmarnock the Main Coal is a best house coal with an analysis

of: Fixed carbon, 52·62; volatile matter, 34·13; sulphur, 0·60; ash, 2·14; water, 10·51. Bunker coals and coals for general steam-raising purposes are somewhat restricted, the majority of the seams yielding house and manufacturing coals.

Girvan.—An isolated narrow basin of Lower Carboniferous strata stretches for about five miles along Girvan Water. Six seams of coal are present, giving a thickness of about 27 feet of coal.

Argyllshire.—An area of about two square miles, composed of coal-bearing Lower Carboniferous rocks, exists on the west coast of Argyllshire at Machrihanish Bay. Eight seams of coal in 288 feet of measures yield 45 feet 9 inches of coal. One seam only is less than 2 feet. There is a probable extension seawards. The available resources are placed at 76,077,100 tons.

DUMFRIESSHIRE.

The River Nith, crossing the Ordovician belt east of New Cumnock, cuts across an isolated area of Coal-measures at Sanquhar; thence turning south, it traverses a patch of Permian rocks at Thornhill, and another somewhat larger expanse of the same rocks around Dumfries. Triassic sandstones underlain by Permian strata, and these by Coal-measures, extend in a south-west direction between Canonbie (p. 247) and the Solway Firth at Annan. The net available quantity of coal remaining unworked in Dumfriesshire is estimated at 453,575,465 tons.

The Sanquhar Coalfield, composed of productive Coal-measures, seventeen square miles in area, fills an irregular hollow of Ordovician strata. A fault of at least 1,200 feet throw bounds the coalfield on the north-east, and many smaller faults traverse the area. Dolerite dykes, sending out sills, invade many of the coal-seams. The chief coals in ascending order are Splint, Twenty Inch, Calmstone, Creepie, from 2 to 5 feet in thickness. On the north-east side of the coalfield Barren Red Measures, overlain by volcanic rocks comparable to the Permian volcanic rocks of Ayrshire, rest unconformably on the productive measures, and are said to be unaffected by a fault of 500 feet throw in the underlying productive measures.

The Calmstone and Splint coals are of good quality.

Midlothian (Edinburgh) Coalfield.

In the number and united thickness of the coals this district surpasses any other coalfield in Scotland.

A well-defined basin fold trending nearly north and south, and enclosing an area of Coal-measures nine miles long and two and a half in width, constitutes one of the most distinctive coalfields of the central valley. The coalfield is rimmed round with Millstone Grits, which rest on richly coal-bearing Lower Carboniferous strata, which are thrown into gentle folds, enclosing the small isolated outliers of Penicuick and Auchencorth on the south, and on the east into more open folds extending into the East Lothians and Haddingtonshire. To the west the coalfield connects by an outcrop of Calciferous Sandstone with that part of the Central Coalfield situated in Linlithgowshire. These coal-bearing Carboniferous rocks lying east of the Pentland Hills, and extending over parts of the counties of Edinburgh, Haddington, and Peebles, is sometimes called the Lothian Coalfield, of which the net available resources are estimated at 2,520,311,573 tons, and thus of nearly equal richness in reserves of coal as the much larger area of the Lanarkshire coal-basin.

The Carboniferous sequence is complete, and is divisible into the undermentioned groups:

Coal-measures	Middle Coal-measures, 450 feet. Lower Coal-measures, 1,300 feet.
Millstone Grit	Millstone Grit (Upper Roslin Sandstone), 400 feet. Millstone Grit (Lower Roslin Sandstone), 200 feet.
Carboniferous Limestone Series	Upper Limestone Group, 550 to 1,070 feet. Edge Coal Group, 550 to 1,000 feet. Lower Limestone Group, 240 to 540 feet.
Calciferous Sandstone Series	Oil Shale Group. Cementstone Group.

Coal-seams in the Calciferous Sandstone Series are thin and impersistent.

The Carboniferous Limestone Series reaches its maximum development in the north-west around Niddrie and the sea-border; in a south-west and east direction all the groups diminish, accompanied by a reduction in number and

thickness of the seams in the Edge Coal Group. In consequence, there is a perplexing change in the nomenclature of the coals and of the limestones. The Great Seam of the Edge Coal Group is generally recognizable throughout, and there is little doubt that the North Coal on the west represents the Parrot Seam on the south-east side, but the correlation of the intermediate coals is uncertain. On the east side of the basin the limestones of the Lower Group are named in descending order, according to a nomenclature adopted for the coast section near Dunbar: No. 3 or Chapel Point Limestone, No. 2 or Skateraw Limestone, No. 1 or Longcraig Limestone; on the west side the descending order is: Bilston Burn Limestone, Vexhim Upper and Lower limestones, North Greens Limestone, Gilmerton Limestone. Several coals appear at different horizons, one of which—the North Green or Jewel Coal, 380 feet below the Bilston Limestone —is regarded as one of the best seams of the coalfield. It consists of thin layers of splint and parrot, with over 3 feet of free coal.

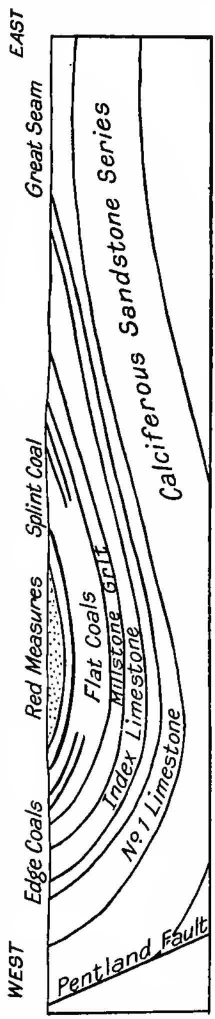


FIG. 50.—SECTION ACROSS THE MIDLOTHIAN COALFIELD. Scale, one inch = 9,000 feet.

The Edge Coal Group, so named from the steep (sometimes nearly vertical) inclination of the seams on the west side of the basin, includes the strata between the top of the Bilston Burn Limestone to the base of the Index (No. 4) Limestone. It attains its maximum development over the northern and central parts of the basin around Niddrie, Gilmerton, Loanhead, and Dalkeith. The united thickness of coal in seams over 23 inches in thickness sometimes amounts to over 80 feet. Along the southern and south-western outcrop the group is thinner. Several seams have died out, or are too thin for profitable working. Taking the Great Seam, Parrot and North coals as identifiable horizons,

the order of the seams on the east and west sides are given in the following table in descending sequence:

West.	East.
Measures, 100–200 ft., with Wood, Flex, Rumbles, and Laverock coals.	Measures, 100 with Deception, Cryne, and Mavis coals.
Great Seam (7 to 10 ft.).	*Great Seam* (7 ft.).
Measures, 700 ft., with Stairhead, Gillespie, Little Gillespie, Little Splint, Perpetual, Corby Craig or Kittlepurse, Little Splint, Big Splint, Real Corby, Carlton, Real Carlton.	Measures, 400 ft., with Diamond, Siller Willie, Blackbird, Coronation or Carberry Jewel, Rough or Smithy, Splint or Garibaldi, Lively, Little Rough or Kailblades.
Blue or North Coal (3 ft.).	*Little Splint or Parrot* (3 ft.).
Measures, 20 to 90 ft.	Measures, 10 to 50 ft.
Bilston Burn Limestone.	Limestone No. 3.

The Carlton, Corby Craig, Stairhead, and Great Seam are important coals in the west, and the Carberry Jewel Coal on the east side.

In the Upper Limestone Group three or four beds of marine limestones with four to six seams of coal interstratified with sandstones recall the Lower Limestone Group. At the base lies the Index (No. 4) Limestone, and the Castlecary (No. 6) Limestone at the top. No. 5 or Arden Limestone lies towards the middle of the sequence, with an 'Extra' limestone between it and the Index Limestone. The South Parrot, an important coal occurring towards the bottom of the sequence, consists of splint coal, 1 foot 10 inches; parrot, 1 foot. The Millstone Grits, that so perfectly outline the basin of Coal-measures, possess little commercial value. On evidence afforded by the vertical distribution of the fossil plants, the series has been subdivided into two parts as shewn in the table (p. 284). In the upper part, with the exception of *Lepidodendron veltheimianum* and *L. glincanum*, the fossil flora is distinct from that of the basal beds. The latter contains a band yielding the peculiar lamellibranch fauna found at this horizon in the Lanarkshire Coalfield and elsewhere in Scotland.

In the south the base of the Lower Coal-measures is taken at the horizon of the Jenny Meggat Coal; in the north at the Seven Feet Coal, 215 feet above the Roslin Sandstone at Joppa, and in the Coal-pits area at the Six Feet Coal, which is 30 feet above the Roslin Sandstone. A twofold arrange-

ment is recognized: a lower set of seams with the Cowpits Coals in the north-east and with the Brunstane Coals in the north-west; and an upper or Craighall group of seams confined to the area north of the Sheriffhall Fault. About 200 feet of measures with thin coals separate the two groups. Coarse, false-bedded red sandstones occur below the Jewel Coal of Whitehall, and above and below the Great Seam. Earthy limestones are developed on different horizons above the Great Seam. One, containing *Spirifer* associated with red and purple shales, is taken as marking the close of the Lower Coal-measures. This bed is found in Dalkeith Park in a position about 460 feet above the Splint Coal of Craighall. Some red measures with compact, unfossiliferous brown limestones, seen in the North Esk above Lugton Bridge, are probably below the horizon of the Craighall Splint.

Coals north of Sheriffhall Fault.

Clayknowes, 3 ft.	Beefie, 6 ft.
Measures, 300 ft.	Measures, 130.
Splint, 5 ft.	Diamoud, 6 ft.
Measures, 60 ft.	Measures, 20 ft.
Rough, 4 ft.	Jewel, 3 ft.
Measures, 55 ft.	

Intervening measures with thin coals about 200 feet.

North-West (*Brunstane Coals*).	*North-East* (*Cowpits Coals*).
Greymecham, 3 ft 7. ins.	Measures, 100 ft., with Spliut, Five Feet, and Quarry coals.
	Glass.
Measures, 110 ft.	Measures, 50 ft.
Salters, 4 ft. with parting.	Barr's, 4 ft.
Measures, 60 ft.	Measures, 20 ft.
Nine Feet, 6 ft. with parting.	Three Feet, 3 ft.
Measures, 30 ft.	Measures, 10 ft.
Fifteen Feet or Ell, 12 ft. 6 ins.	Six Feet, 4 ft. 6 ins.
Measures, 145 ft.	
Four Feet, 4 ft.	
Measures, 60 ft.	
Seven Feet, 17 ft., two partings.	

An excellent section of Coal-measures is laid open to inspection along the foreshore at Joppa.

Skipsey's Marine Bed, consisting of a dark grey calcareous band about 2 feet thick, is exposed a little above the junction of the North and South Esk. Its probable position is about 460 feet above the position of the Splint Coal of Craighall, and has yielded the following fossils: *Chonetes hardrensis*, *Spirifer* sp., *Porcellia* (?) *Orthoceras* sp. The red barren Middle Coal-measures of Dalkeith Park consist of

coarse-grained, brown, and red sandstones mixed with red, lilac, grey, and mottled clays, with a thin calcareous zone about 230 feet above the base.

Palæontologically the Upper Limestones are not distinguishable from the Lower Limestones by the presence of peculiar species of invertebrata, but by the absence of many widely spread Lower Limestone forms. Little is known of the vertical distribution of *Carbonicola*, *Anthracomya*, and *Naiadites*, and certainly not sufficient to warrant a zonal order of their occurrence.

The Great Pentland Fault bounds the Midlothian basin on its west side. Near Gilmerton a compound syncline forces the outcrop of the Limestone Group west of its north and south line, with a reversal of the beds close to the Pentland Fault. High dips prevail along this western side. On the east side of the main basin an anticlinal fold trending north-north-east brings up the Lower Limestone Group of Roman Camp with the Edge Coal Group dipping south-south-east into the East Lothian Coalfield. The chief dislocations met with in the Coal-measures trend approximately east and west, with their maximum displacements towards the centre of the trough. Of these, the Sheriffhall Fault, with a downthrow north of 500 feet, and the Vogrie Fault, with a downthrow north-west of 250 feet, are the more important.

Towards the centre of the basin the coals rapidly flatten, but not before reaching considerable depths. The Great Seam of the Limestone Group, for instance, is 2,756 feet below the surface on the upthrow of the Sheriffhall Fault, and 3,500 feet on the downthrow side of this fault. Though not quite free of igneous intrusions, the coalfield is less affected in this way than other Scotch coal-bearing areas. In fact, east of the Pentland Fault the igneous intrusions are limited to a few east and west dolerite dykes resembling the Whin Sill in composition.

The majority of the coals both in the Limestone Groups and in the Coal-measures are bituminous. Parrot (cannel) coal is general, and forms an important constituent of several seams. A few years ago the Great Seam of Niddrie, with a thickness of 8 feet, was worked mainly for its cannel band (2 feet), and the rest of the coal was not brought to bank. Two of the best coals, North Greens and South Parrot, occur outside the main coal-bearing group. The Arniston Parrot Seam of the Edge Coal Group contains a cannel band from

6 to 9 inches thick, yielding 68 gallons of crude oil and 54 pounds of ammonium sulphate to the ton. An analysis gives: Volatile matter, 54·20; fixed carbon, 42·48; sulphur, 0·22; ash, 3·10; yield of gas, 14,135 cubic feet per ton. The Stairhead Seam of Niddrie is a compound seam containing bands of steam coal, cannel and black band ironstone. The cannel ranges up to 2 feet 6 inches, with an analysis of: Volatile matter, 41·30; fixed carbon, 52·20; sulphur, 0·33; ash, 6·17; gas yield, 10,805 cubic feet per ton. In the same district a cannel band in the Great Seam yields 12,330 cubic feet of gas per ton. Seams or parts of a seam, termed 'jewel,' generally furnish best house coal. One of these in the Parrot Seam of Newbattle has a composition of: Volatile matter, 41·41; fixed carbon, 55·72; sulphur, 0·31; ash, 2·58. Coals termed 'splint' furnish steam, house, or gas coal. Seams worked in the Lower Coal-measures are Four Feet, Fifteen Feet, Nine Feet, Jewel. At the New Craighall Colliery the Fifteen Feet Coal consists of: Coal, 4 feet 10 inches; fireclay, 9 inches; coal, 4 feet; ironstone, 5 inches; coal, 7 inches. In the same locality the Nine Feet Coal (5 feet thick) gives an upper jewel part with an analysis of: Volatile matter, 50·50; fixed carbon, 46·98; sulphur, 0·36; ash, 2·16; and a lower splint part of the following composition: Volatile matter, 46·88; fixed carbon, 45·79; sulphur, 0·43; ash, 6·90.

Haddingtonshire.—The Carboniferous Limestone Series of the Midlothian basin rises on the east along the flanks of an anticline ranging north and south from Roman Camp near Gorebridge to Prestonpans. Along the eastern flanks of this anticline the Limestone Coal Group occupies a shallow basin with gentle dips. The highest seam, 60 feet below the Index Limestone, is called the Great Seam, and corresponds with the Great Seam of Midlothian. In descending order beneath it are the following coals: Splint (4 feet), Parrot ($2\frac{1}{2}$ feet), Three Feet ($2\frac{1}{2}$ feet), Four Feet (3 feet), Five Feet (2 to 5 feet), Pencaithland Splint ($2\frac{1}{2}$ feet), Rough (2 feet), Hauchielin (2 feet), the last lying 70 feet above the top of the Lower Limestone Group.

Cover.—Boulder clay, and in a much less degree glacial sands and gravel, cover wide areas and have obliterated much of the pre-glacial landscape. The Palæozoic formations, indeed, are laid bare only in river gorges, on the sea-shores, on the Roman Camp Hill, and in quarries.

Firth of Forth.—The Firth of Forth truncates the Midlothian basin between Portobello on the west and Preston-

pans on the east. On the opposite northern banks of the Firth the Fifeshire basin is similarly breached by the sea. So far as is known the bed of the Firth consists of a thick deposit of boulder clay, while the depth of water is mostly under 20 fathoms. Thus the conditions are eminently suitable for undersea mining. By joining up the outcrops on the north side along the Fifeshire coast with those on the south side on the Lothian coast, an area of about 130 square miles has been mapped out, estimated to contain a reserve of 2,442,960,000 tons. Areas are leased, and coal is being won opposite Prestonpans and between Dysart and Leven. The coals of the Edge Coal Group on the Fifeshire coast are not so well developed as at Joppa; but, on the other hand, the coals of the Fifeshire Coal-measures are better developed than on the Midlothian shore.

Sutherlandshire.

A small coalfield of Jurassic age occurs along the sea-coast at Brora. It is possible that the coal may extend over an area of three or four square miles, and that there exists an available supply of at least 1,000,000 tons of coal in seams of 24 inches and upwards.

CHAPTER XXIII

THE COALFIELDS OF IRELAND

A GEOLOGICAL map shows that the greater part of Ireland is largely composed of Lower Carboniferous strata resting on older formations. Coal-measures are represented in small detached areas in the north and to a larger extent in the south.

The north-east and south-west structural lines, determining the orientation of the coalfields in the Northern Province of Great Britain, extend across the North Channel into Antrim and County Mayo, and the east and west tectonic lines of the Southern Province are continued across St. George's Channel into Queen's County, Limerick, Cork, and Kerry.

Coal-measures are found within the folds belonging to these general lines of structure, but the equivalents of the Coal-measures of the Midland Province of England have been entirely swept away—if, indeed, they ever existed—over Central Ireland.

The extent of the coalfields of Ireland has been estimated at 79,090 acres, and the total coal tonnage at 204,107,700, or under 3,000 tons per acre—that is, less than the quantity contained in an acre of coal 3 feet in thickness. Between 1880 and 1892 the production amounted to 2,542,000 tons, an average of 110,521 tons per annum. In 1905 the output fell short of 100,000 tons.

Concurrently with the distribution of the Carboniferous rocks the seams vary in character. In the north they are bituminous, and are found in the Lower Carboniferous strata as well as in the Upper Carboniferous. In Southern Ireland the seams are semi-bituminous or anthracitic, and belong to the Upper Division of the Carboniferous, agreeing both in age and character, though much less developed, with the coals of South Wales.

The area of productive Lower Carboniferous measures in northern Ireland, excepting possible extensions under the

newer formations of Antrim, is of limited extent, while in Munster, where the Upper Carboniferous formation attains its greatest development, it is the lower or least productive subdivision that forms the greater part of the coalfield.

Black shales, but containing impure, earthy limestones ('calp'), met with in the Lower Carboniferous rocks, so closely resemble the productive Coal-measures that they are still frequently mistaken for them; but they may be readily recognized by the presence of *Posidonomya becheri*, Goniatites of a Lower Carboniferous facies, and other Lower Carboniferous fossils.

The principal Irish coalfields are those of West Munster, East Munster, Leinster, Connaught, and Tyrone, of Upper Carboniferous age; and the small coalfield of Ballycastle belonging to the Lower Carboniferous formation.

In point of size the West Munster Coalfield is the largest, but the lowest measures (marine), rarely containing coals over 2 feet in thickness, occupy the greatest area. The highest measures in the Black Water Valley and County Cork contain two coals at the summit, known as South or Harris's Bulk Vein, and the Bulk Vein, from 5 to 7 feet in thickness, resulting from the union of two or more seams.

In East Munster the highest measures are estimated to be 1,300 feet thick, containing the Clashacona and Parknaclea seams at the top. The first named, averaging 2 feet in thickness, is described as a good anthracite, but with a bad roof. The Parknaclea Coal, 4 feet thick, has been exhausted. In Leinster the highest measures are considered to occur in the Castlecomer Coalfield, which contains five seams, giving a total thickness of 9 feet of coal distributed through 700 feet of strata. Between this coalfield and the districts of Coolbaun and Newtown is a fault with an upthrow west. Five seams are recognized at Coolbaun and Newtown, the best known being the Jarrow Coal, varying in thickness from 3 inches to 6 feet. Numerous fossil fishes have been obtained from a thin band of carbonaceous shale forming the roof.

The chief coalfields of County Tyrone are those of Dungannon and Coal Island, containing several seams, among which are the Annagher Coal (7 to 9 feet), the Blackaveel Coal (5 feet), the Derry Coal (4 feet 6 inches), and the Drumglass Main Coal (4 feet). Very little coal-mining is at present being carried on in this district, but attempts by boring to prove the extension of the Coal-

measures are being made in the Lough Neagh area. The exposed coalfield is intensely faulted, and it is uncertain to what extent the concealed basin will be faulted and what allowance it is necessary to make for spoliation by igneous intrusions. The thickness of cover is also uncertain.

The Coal-measures of Ballycastle, County Antrim, are compared with the Edge Coals of the Lower Carboniferous rocks of Scotland. Three seams were formerly worked, but the coalfield is now regarded as practically exhausted.

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